TIE WORKSHOP:

„ADVANCED TOPICS IN ELECTRONIC ASSEMBLING TECHNOLOGY"

Design and Measurement of Integrated Passive Devices on Flexible Substrates

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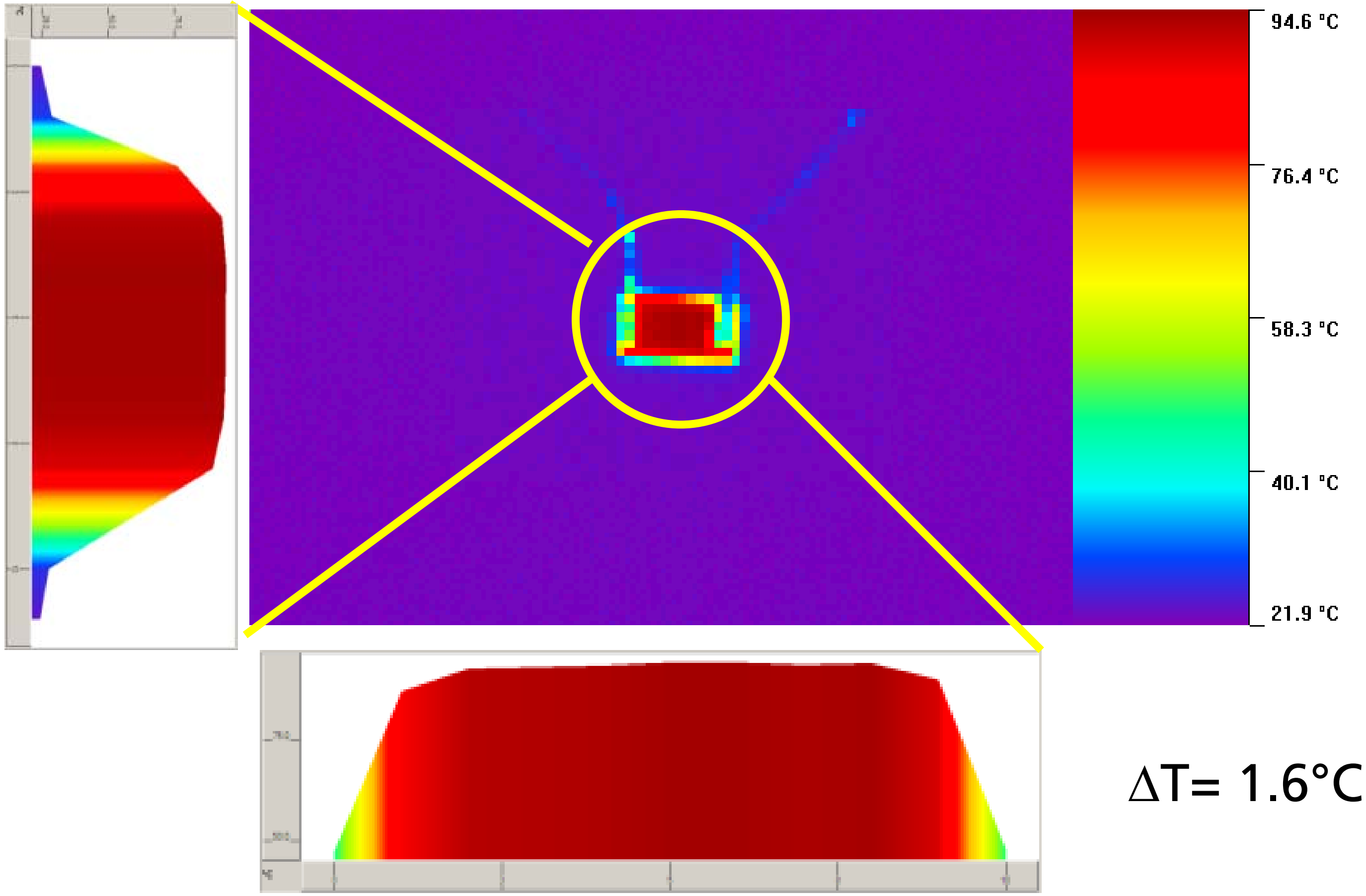
Content

- Introduction to integrated passive devices on flexible substrates
  - Comparison with discrete chip size passives
- Design rules for integrated passive devices on flexible substrates
  - Thick film passive devices
  - Thin film passive devices
- Realization of integrated passive devices on flex. substrates, R2R
- Measurement of integrated passive devices on flexible substrates
  - Carbon based polymer resistive devices
  - Intrinsically conductive polymer devices (PEDOT:PSS)
  - Planar capacitive structures
  - Interdigitated capacitive structures
- Summary and conclusions

Temperature Profile Thick Film Chip Resistor

ΔT= 2.0°C



ΔT= 1.6°C

Uniform temperature thick film chip resistor, size 0805

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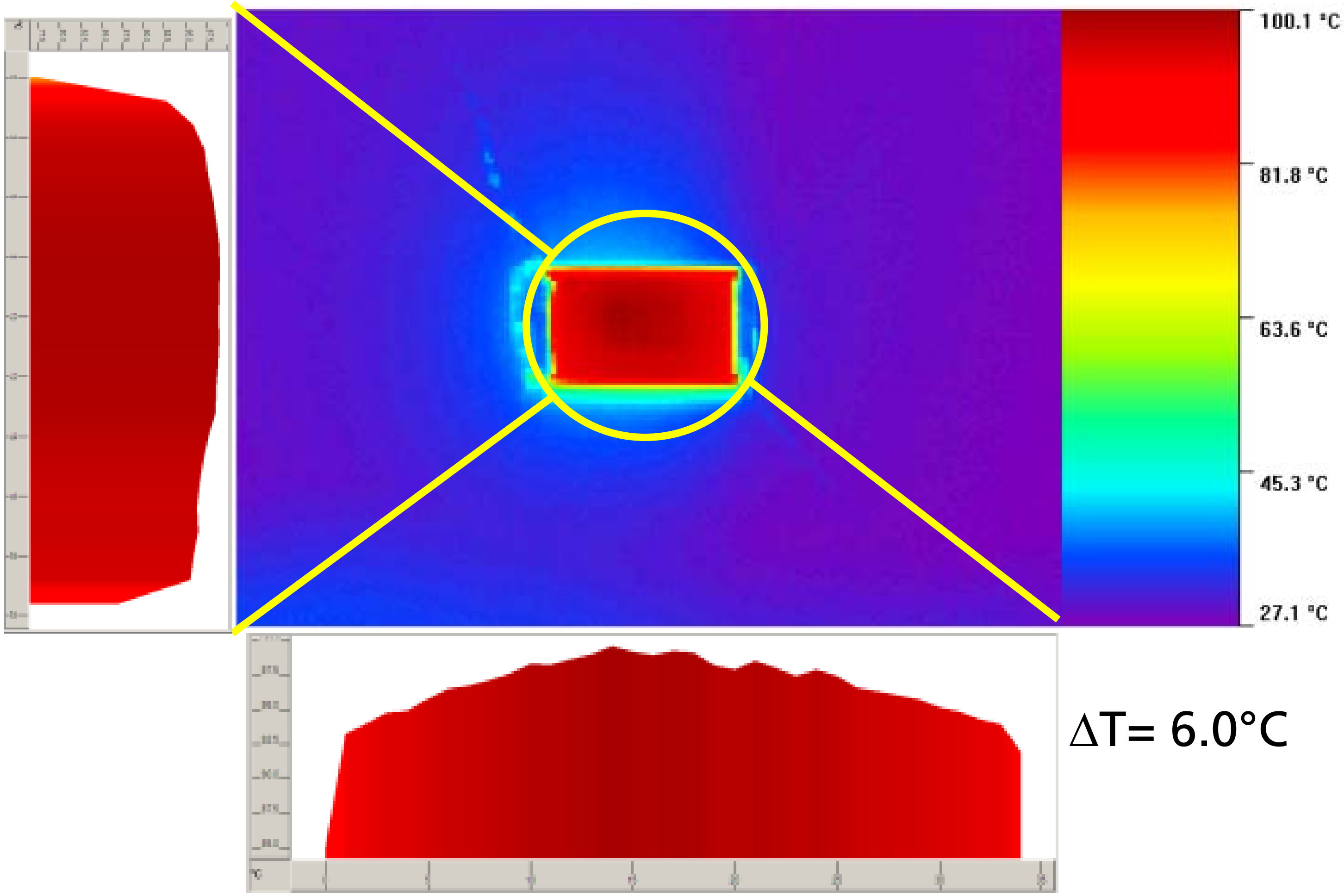
Temperature Profile Thick Film Chip Resistor

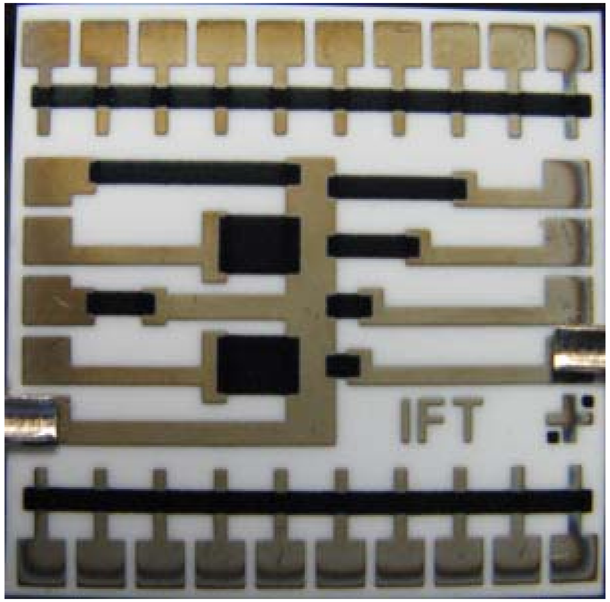
ΔT= 6.0°C

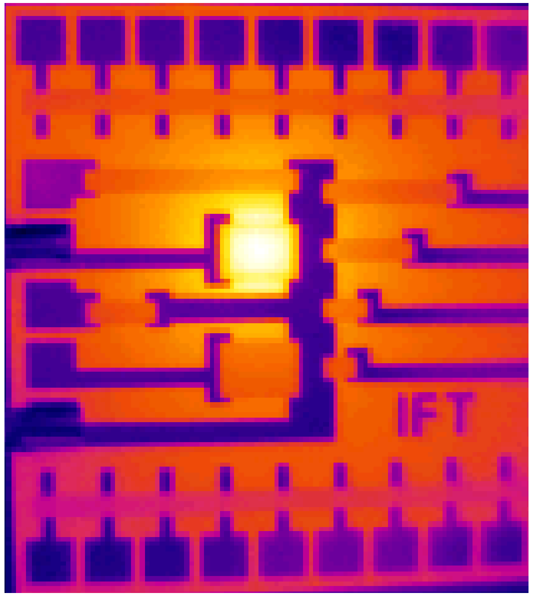


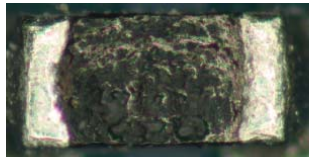
ΔT= 6.0°C

Uniform temperature thick film chip resistor, size 2512

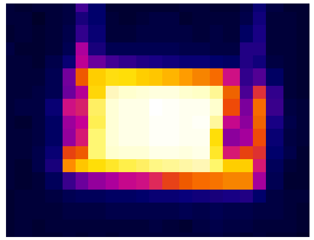
Thick Film RuO_2 Resistors on Al_2O_3







c)

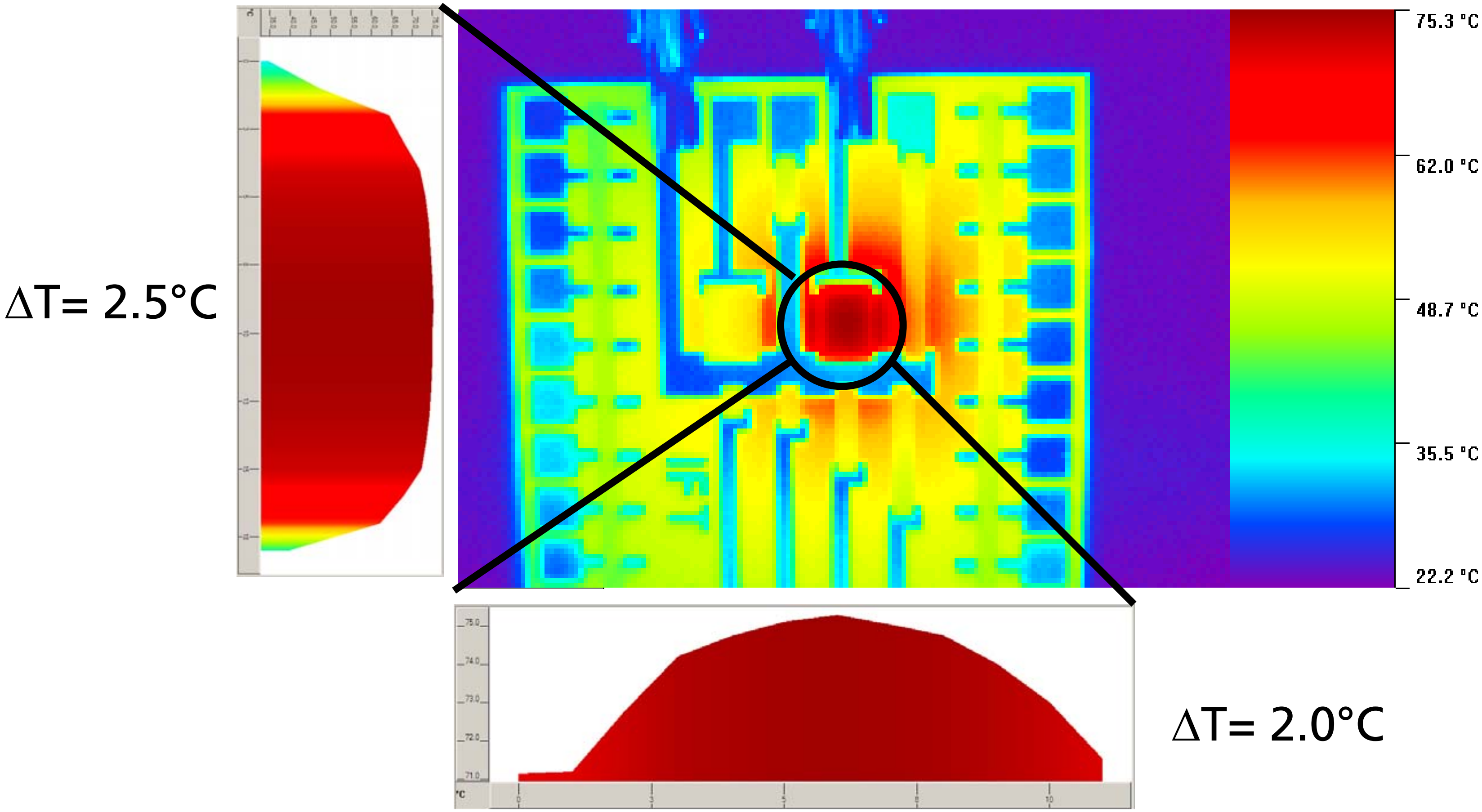


d)

Thick film resistor, screen printed on Al_2O_3 substrate, size 25.4 x 25.4 mm²
c) Optical view
d) IR view

Thick film chip resistor, size 0805, on Al_2O_3 body,
c) Optical view
d) IR view

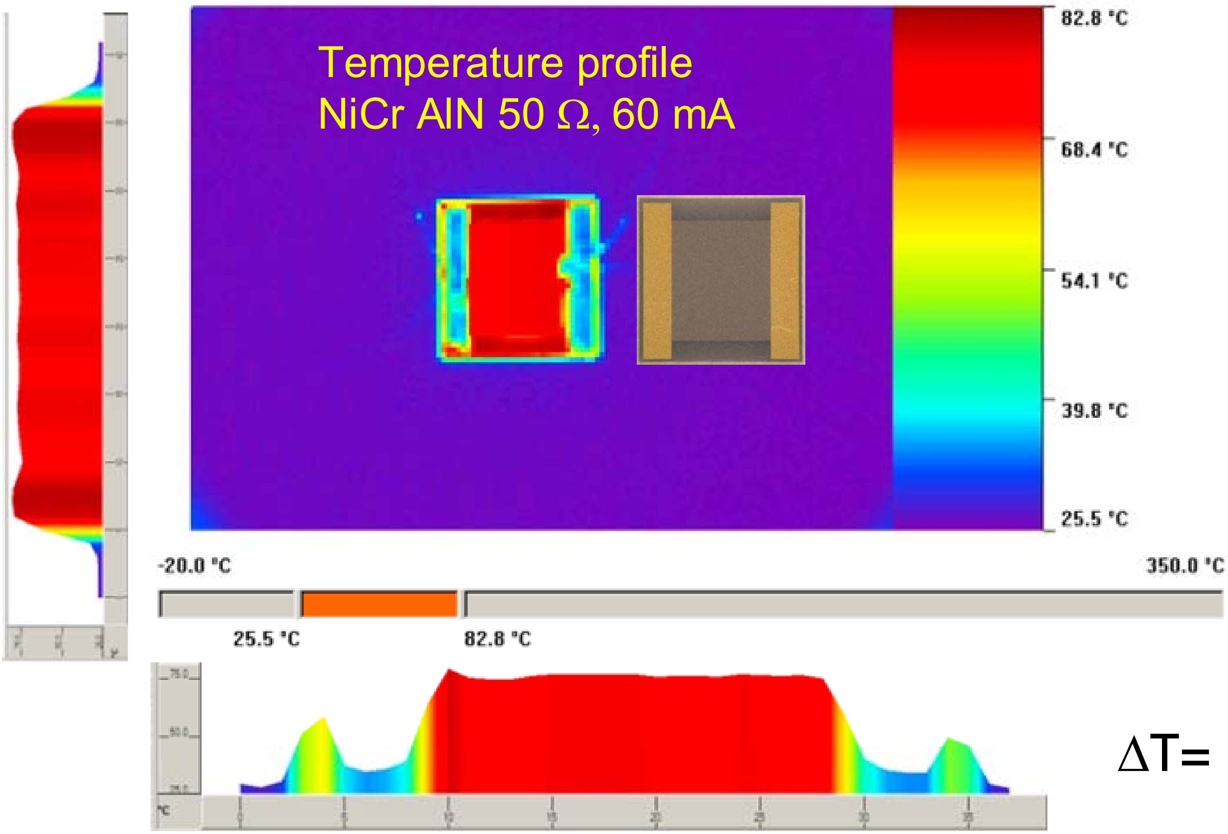
Temperature Profile Thick Film RuO_2 on Al_2O_3



Uniform temperature profile of thick film resistor, size 2000x2000 μm², R100 Ω/□, Al_2O_3 substrate

Temperature Profile Thin Film NiCr on AlN

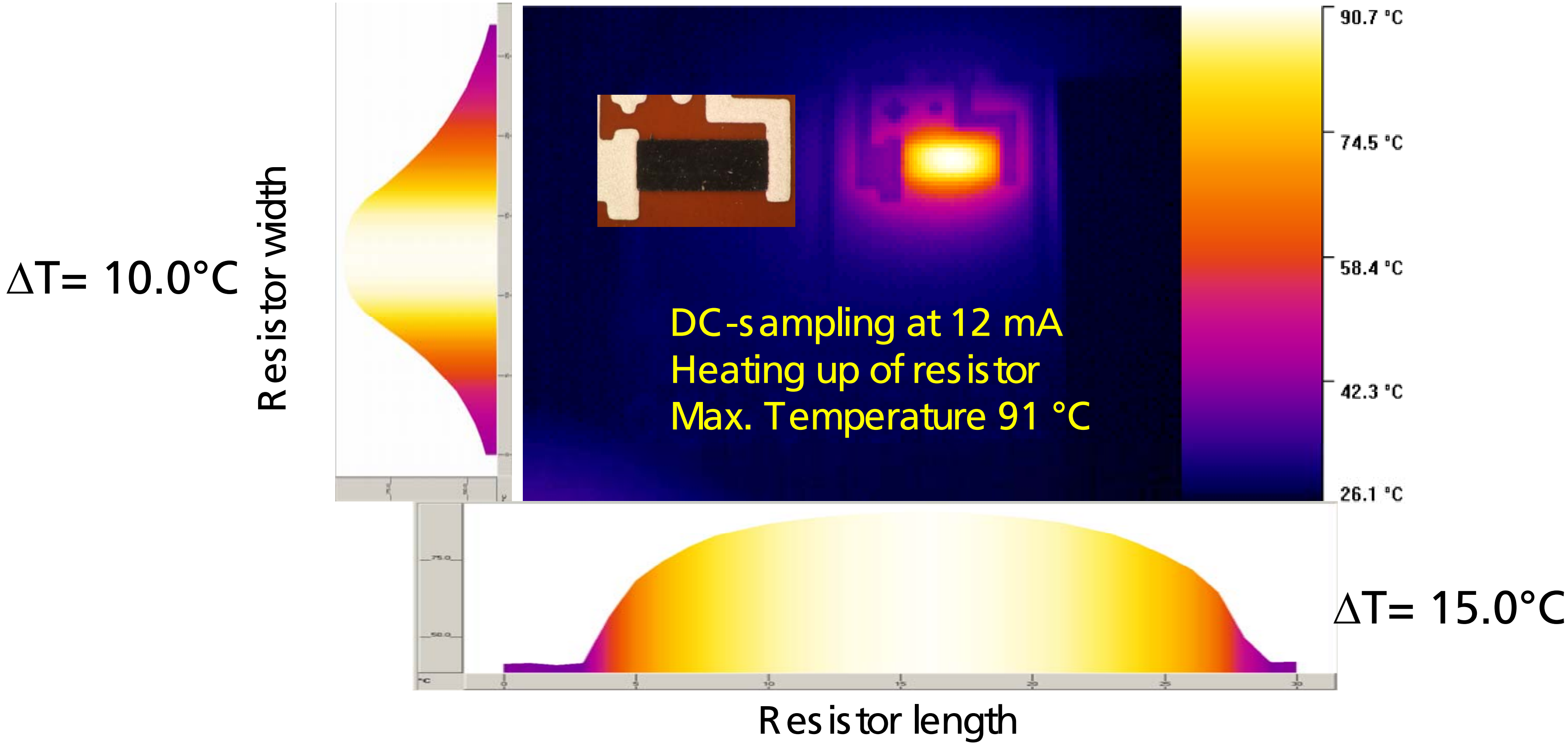
ΔT= 2.0°C



ΔT= 2.0°C

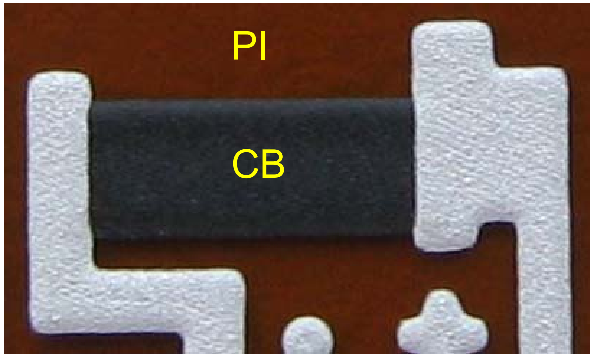
Uniform temperature profile at 60 mA current sampling of thin film NiCr chip resistor, size 4000x3000 µm², R50 Ω/□, AlN substrate

Temperature Profile of Polymer Resistor on Foil



Temperature distribution during self- heating of flexible thick film polymer resistor on PI foil, hot spot in the center of the resistive layer. Higher temperature gradient along and across the resistive layer

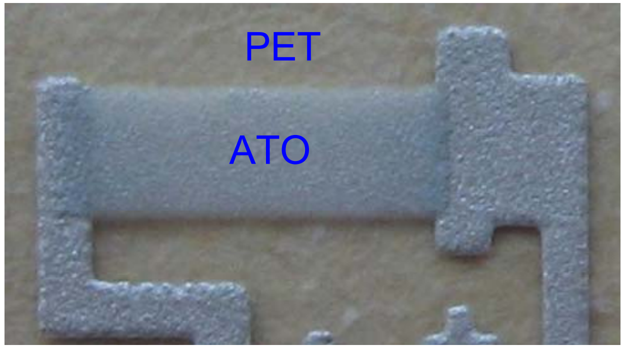
Polymer Resistive Layers



a)

b)

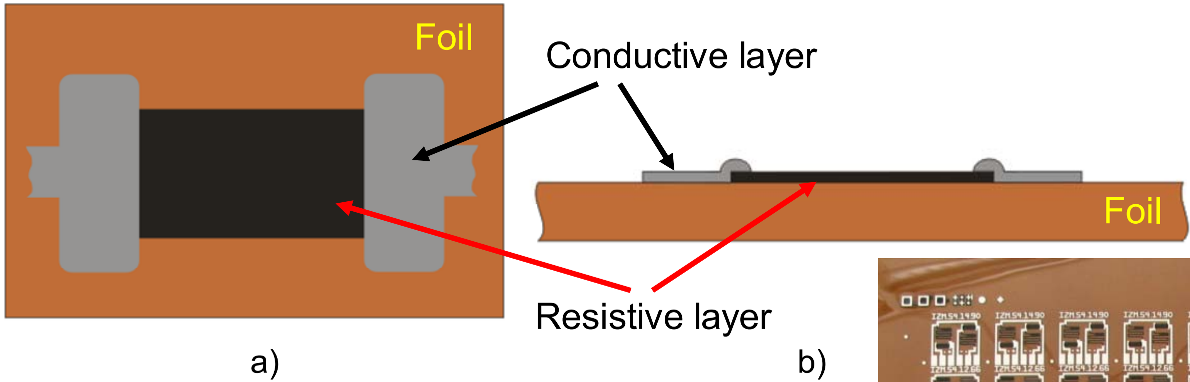
c)



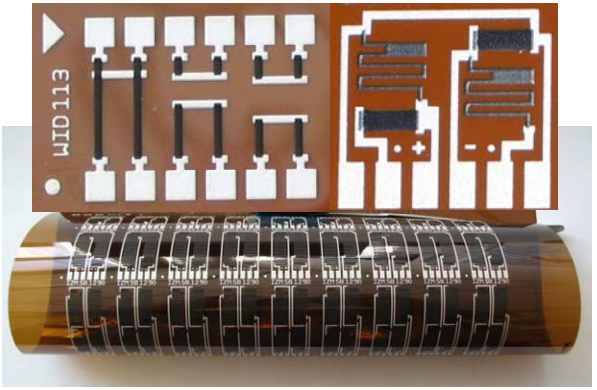
d)

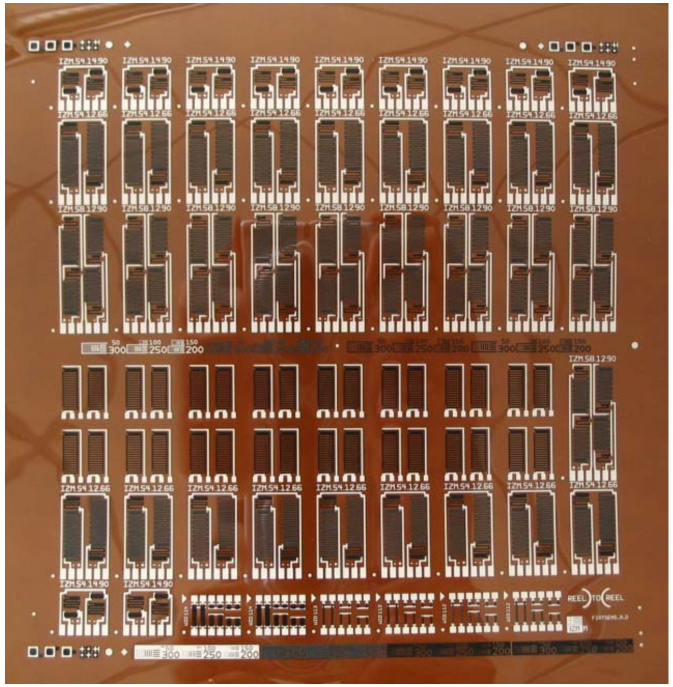
Polymer film resistive structures on foils (3.55 x 1.4 mm²):
a) Carbon filled polymer on PI, b) Carbon filled polymer on PET
c) PEDOT:PSS on PET, b) ATO on PET

Polymer Resistive Layers



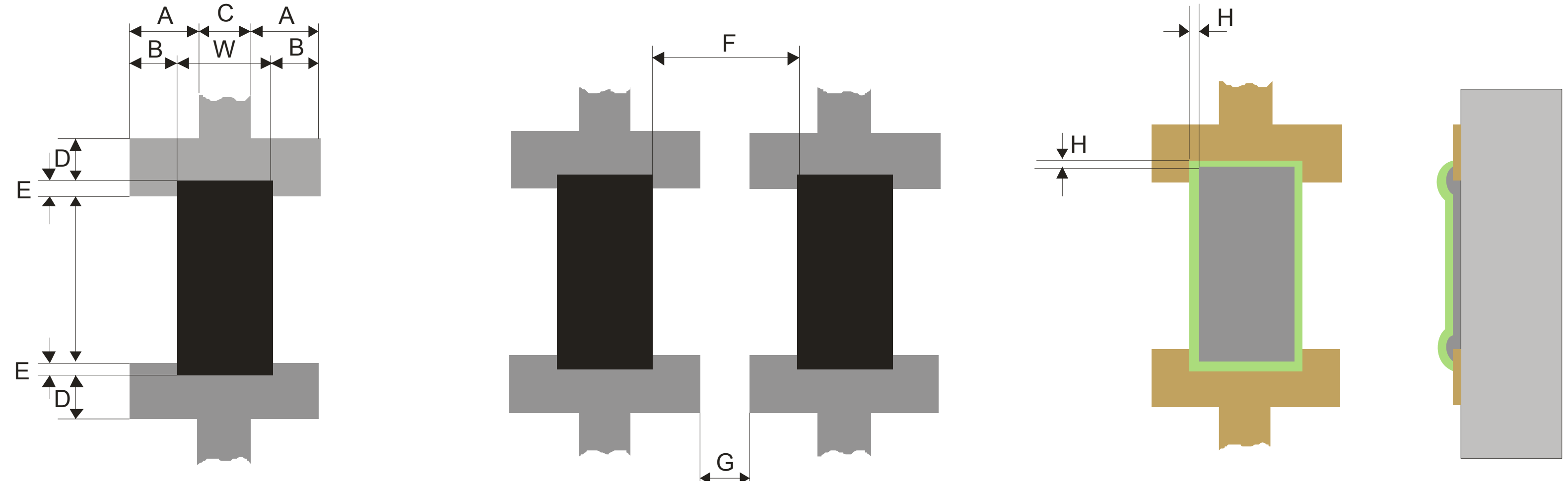
Polymer film resistive structure on foil
a) top view, b) cross section





Polymer film resistive structures on polyimide foil (PI), overview.

Design Rules Thick Film Polymer Resistive Layers



Geometry Type	Min. [µm]	Preferred [µm]	Comment
A	250 to 5200	625 to 2600	
B	125	250	
C	125	250	Interconnection conductor
D	125	250	
E	125	250	Resistor-conductor pad overlap
F	500	1000	Resistor- resistor distance
G	250	500	Pad- pad distance
W	500 to 10000	1000 to 5000	Resistor width
L	500 to 10000	1000 to 5000	Resistor length
L/W	0.3 to 10	0.5 to 5	L/W ratio

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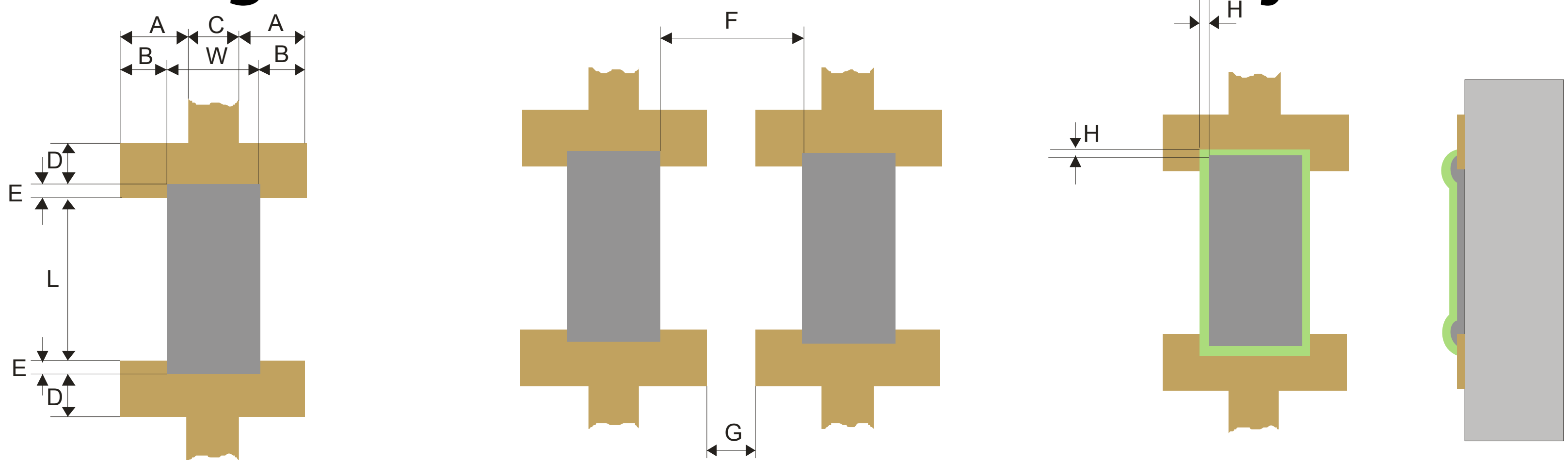
Design Rules Thin Film Resistive Layers



Geometry Type	Min. [µm]	Preferred [µm]	Comment
A	250 to 5200	625 to 2600	
B	25	50	
C	25	50	Interconnection conductor
D	25	50	
E	25	50	Resistor-conductor pad overlap
F	50	100	Resistor- resistor distance
G	25	50	Pad- pad distance
W	25 to 10000	50 to 5000	Resistor width
L	25 to 10000	50 to 5000	Resistor length
L/W	0.1 to 20	0.25 to 10	L/W ratio

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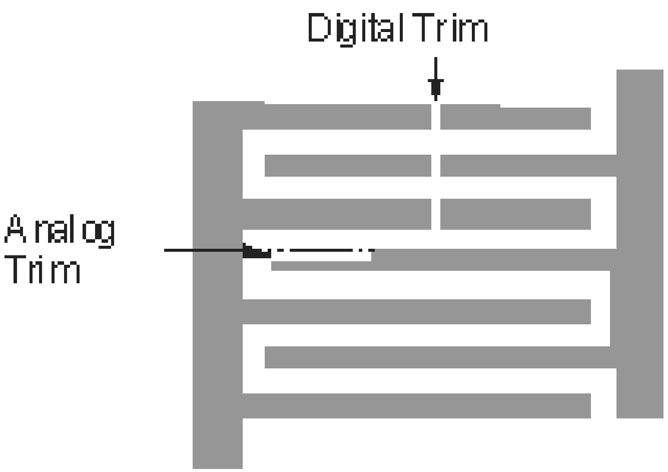
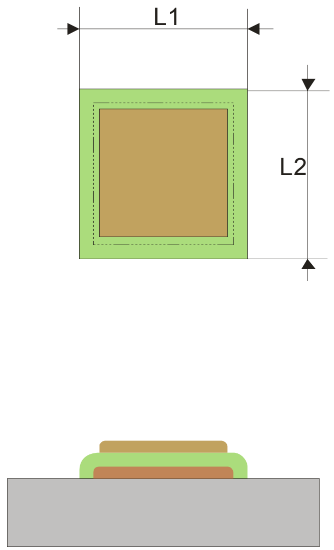
Design Rules Capacitive Structures



Interdigital Capacitor



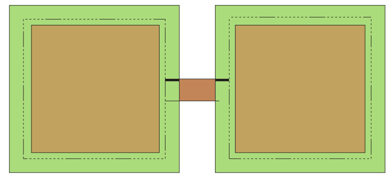
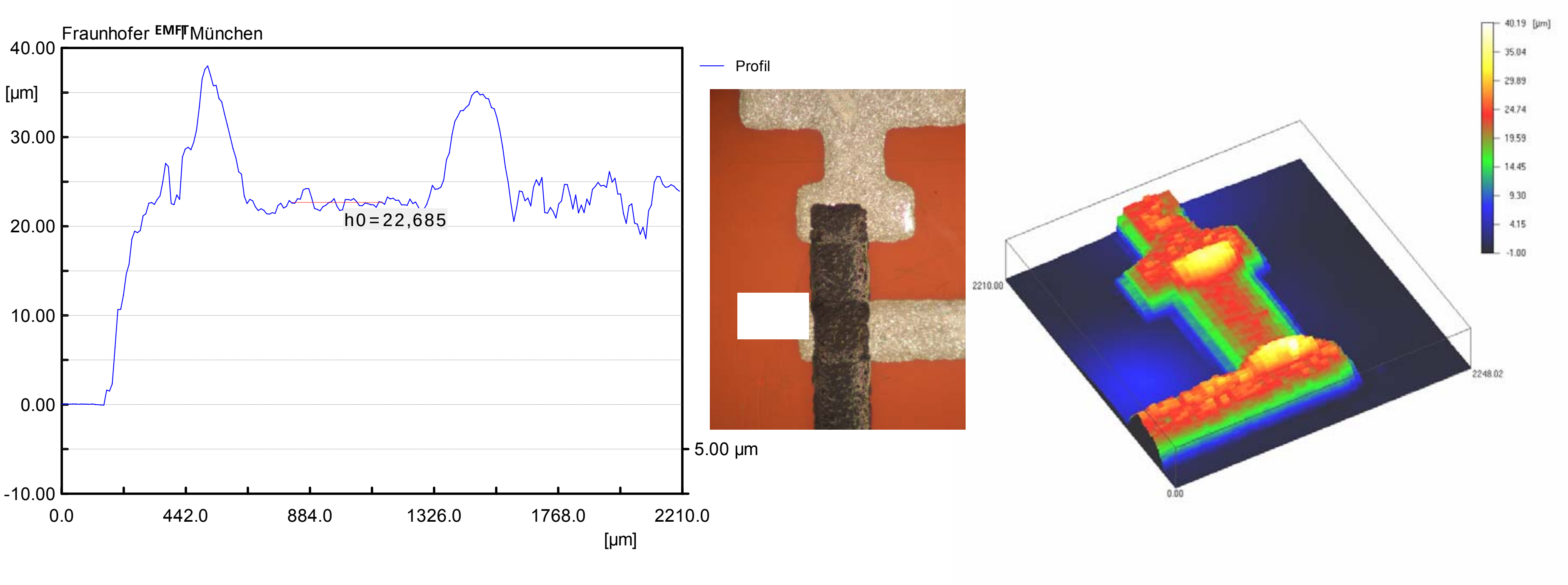


Plate capacitor

L_1 and L_2 of the dielectric should exceed the bottom electrode with at least 250µm

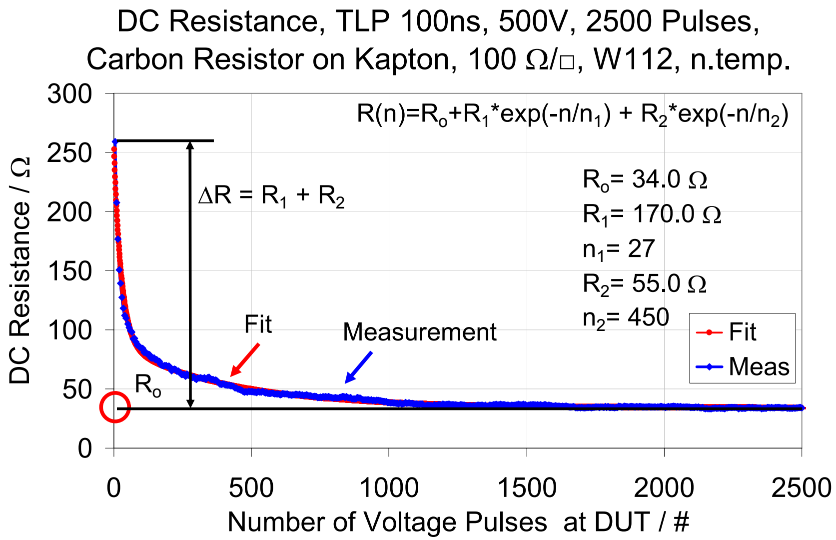
Layout of Flexible Thick Film Polymer Resistor

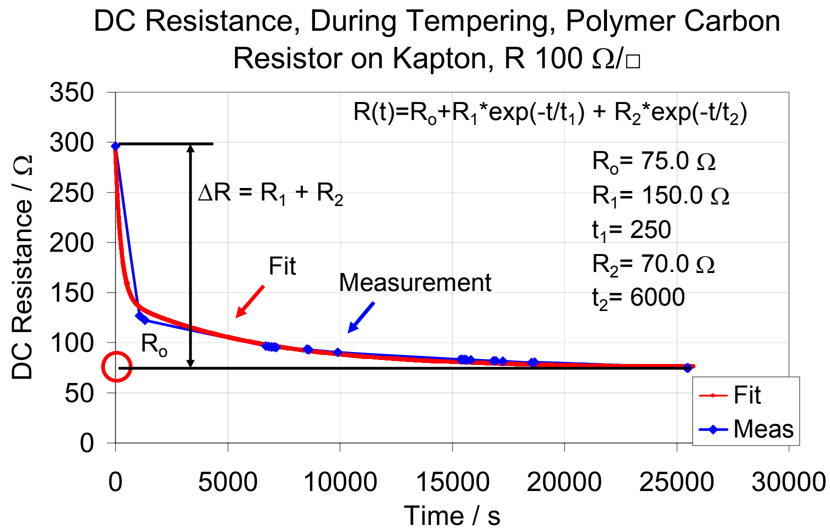


Scanned profile of flexible polymer resistor (L=W= 700 µm, h=23 µm)

Annealing at Constant Temperature vs. Electrical Pulsing with Constant Amplitudes

Resistor not tempered





DC- resistance versus number of applied pulses, TLP- voltage 500V, pulse width 100 ns, 2500 pulses

DC-resistance change versus time during annealing at 150°C

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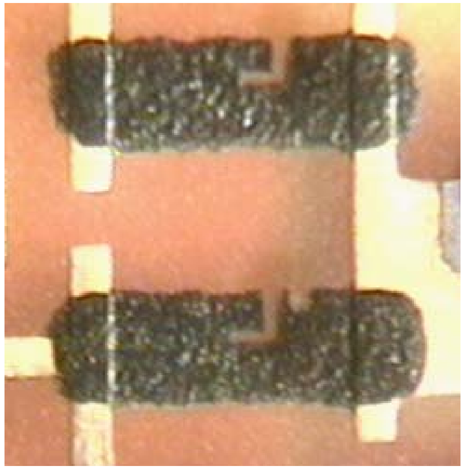
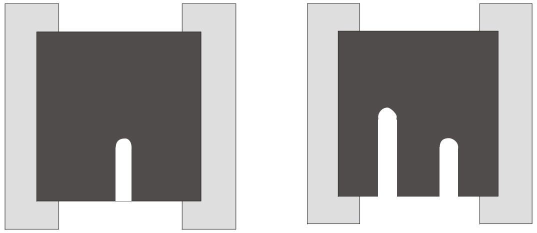
Laser Trimming of Polymer Resistors



Laser-Trimm cut shape of the carbon loaded poly epoxy thick film resistors (source: AEPT-Report, ESI, Feb. 2002)



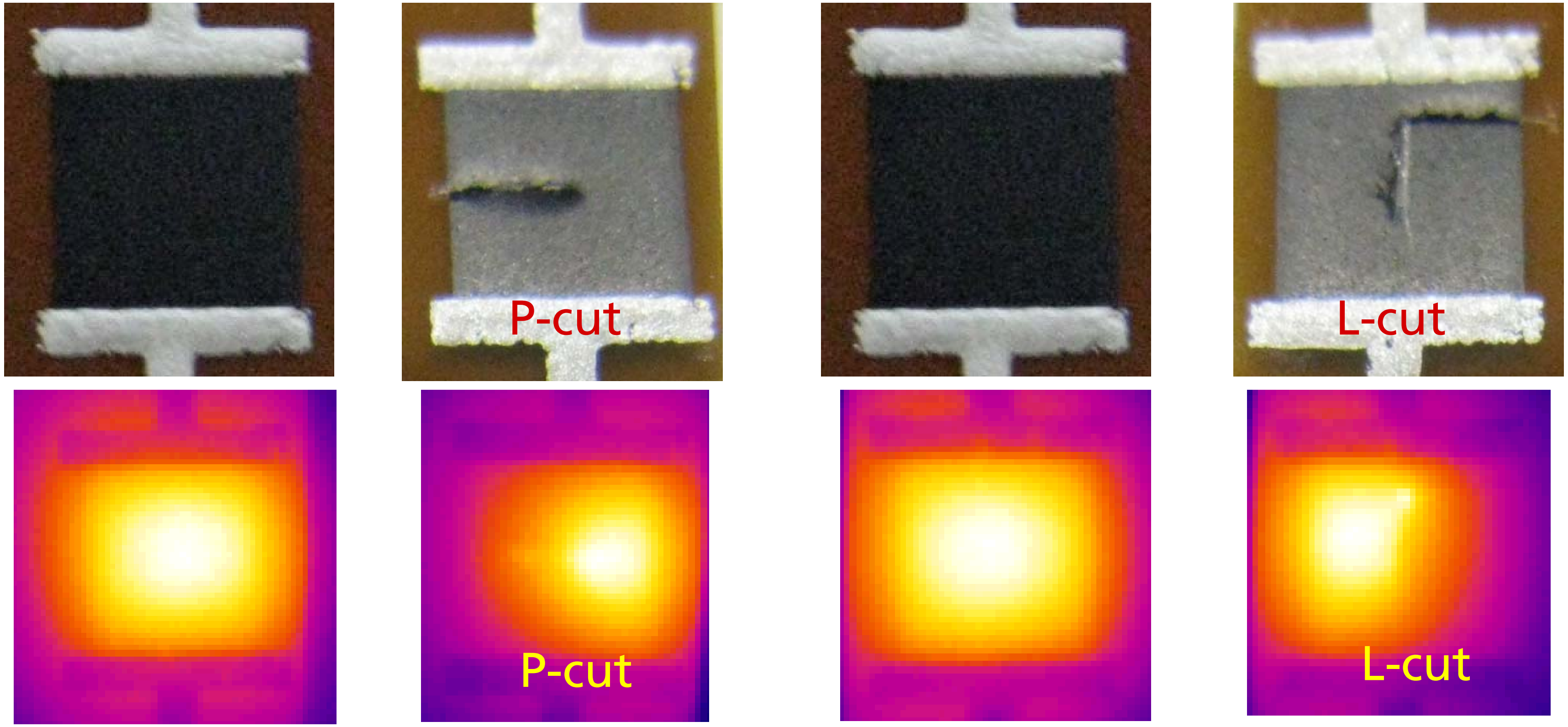
Single, double Plunge-cut

L-cut

Serpentine-cut

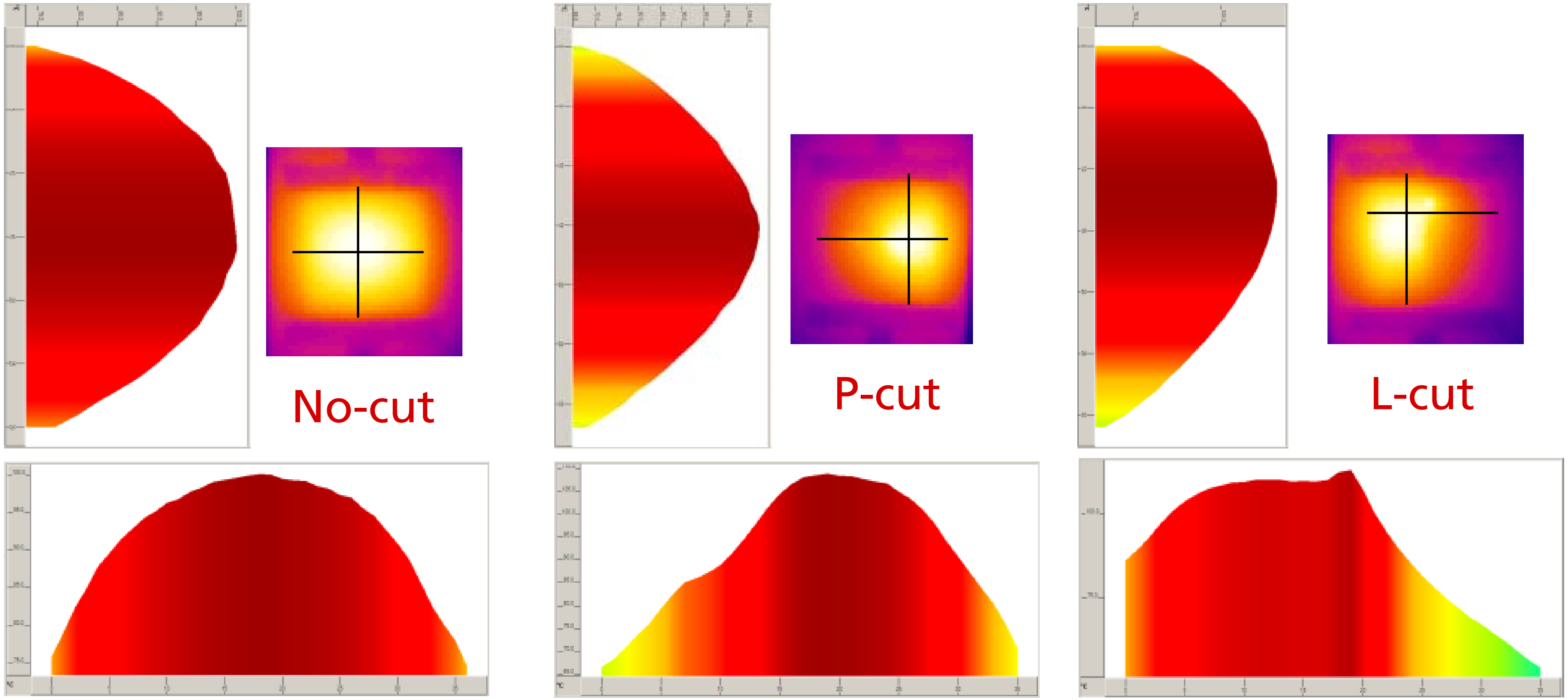
Scan-cut

Temperature Profile after Laser Trimming



Temperature distribution (IR images) before and after laser-trimming during self- heating of flexible thick film polymer resistor on PI foil,
Hot spot in the center of the resistive layer before trimming.
Hot spot moved from the center of the resistive layer after trimming

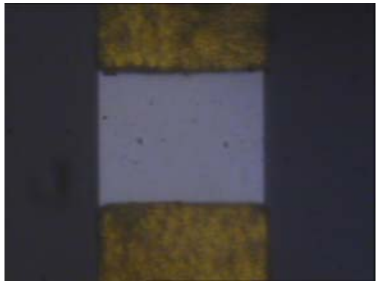
Temperature Profile after Laser Trimming



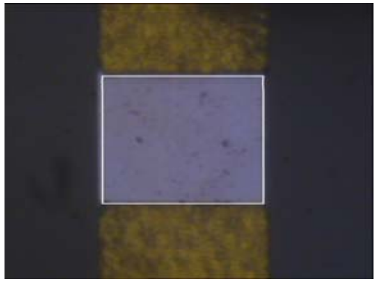
Cross sections of temperature distribution (IR images) before and after laser-trimming during self- heating of flexible thick film polymer resistor on PI foil,
Hot spot in the center of the resistive layer before trimming.
Hot spot moved from the center of the resistive layer after trimming

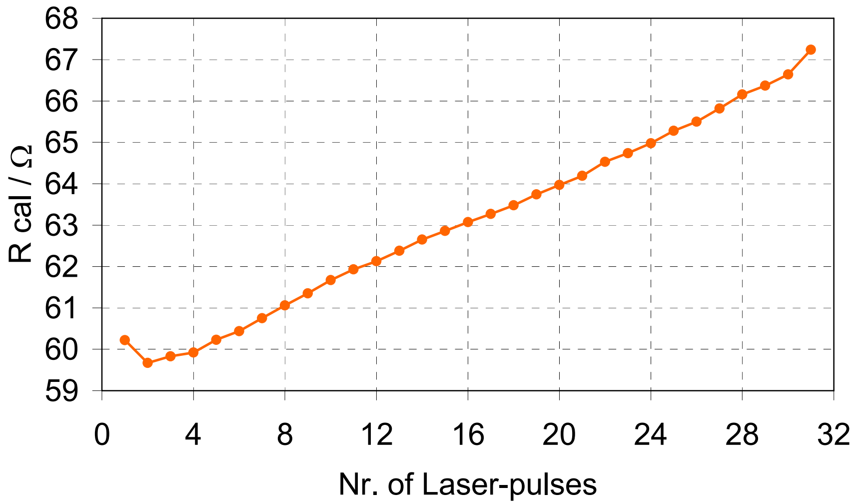
Laser Trimming of Thin Film Resistors

0 Pulses



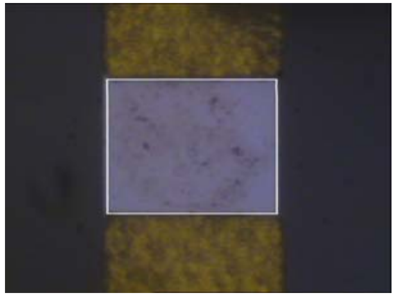
10 Pulses



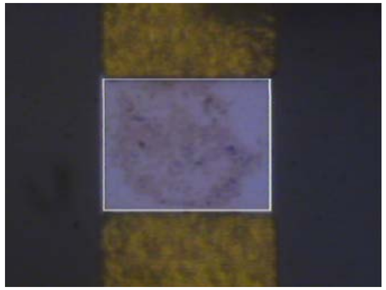


Thin film NiCr-Resistance change after trimming with single laser-pulses

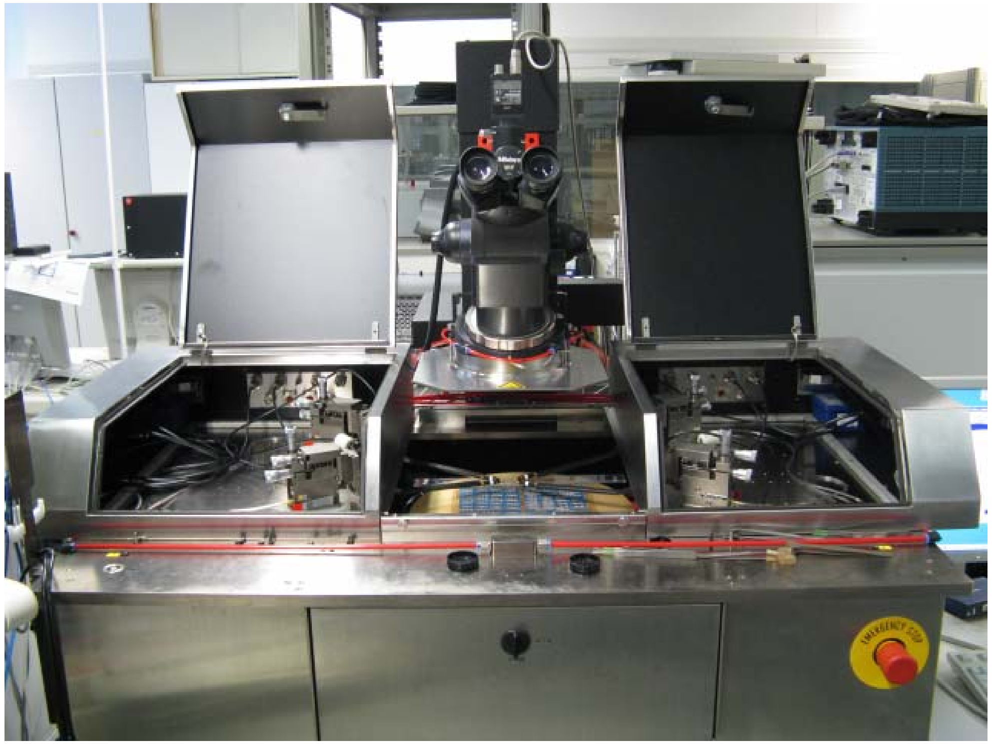
20 Pulses



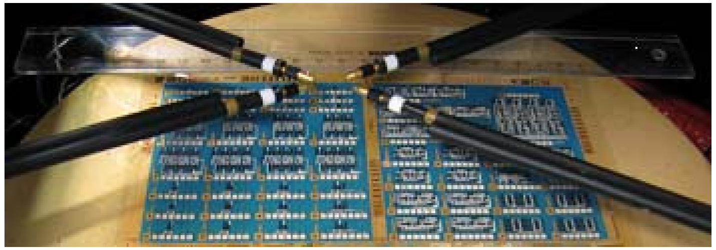
30 Pulses



DC Electrical Stress and Measurement Equipment

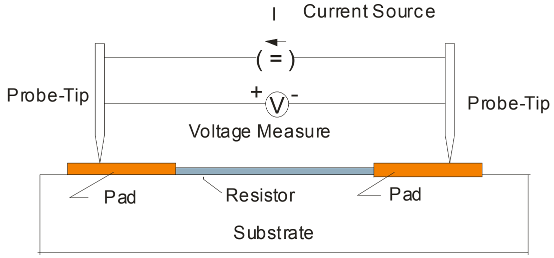


Shielded probe station (PA300) used for organic electronics measurements

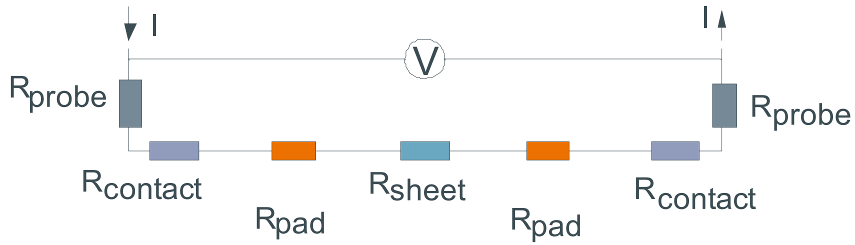


Triax-probes used for contacting polymeric devices and systems

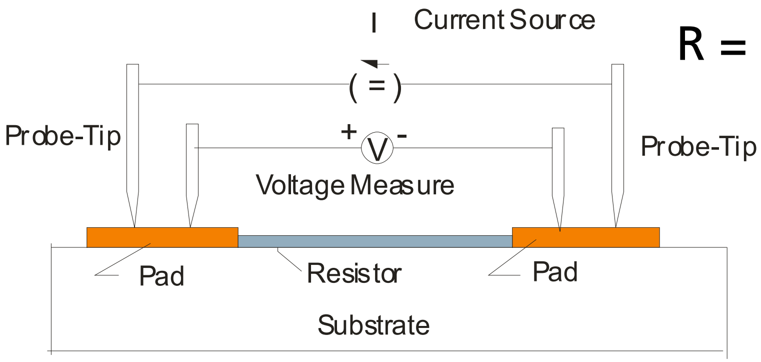
DC Electrical Stress and Measurement Modes



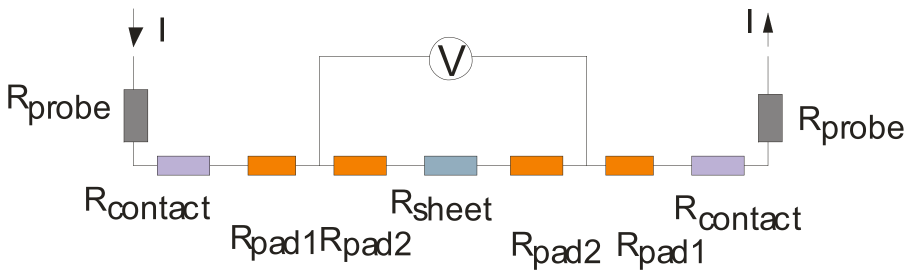
$$R = V/I = R_{sheet} + 2R_{pad} + 2(R_{contact} + R_{probe})$$



Two point measurements



$$R = V/I = R_{sheet} + 2R_{pad}/2$$



Four point measurements

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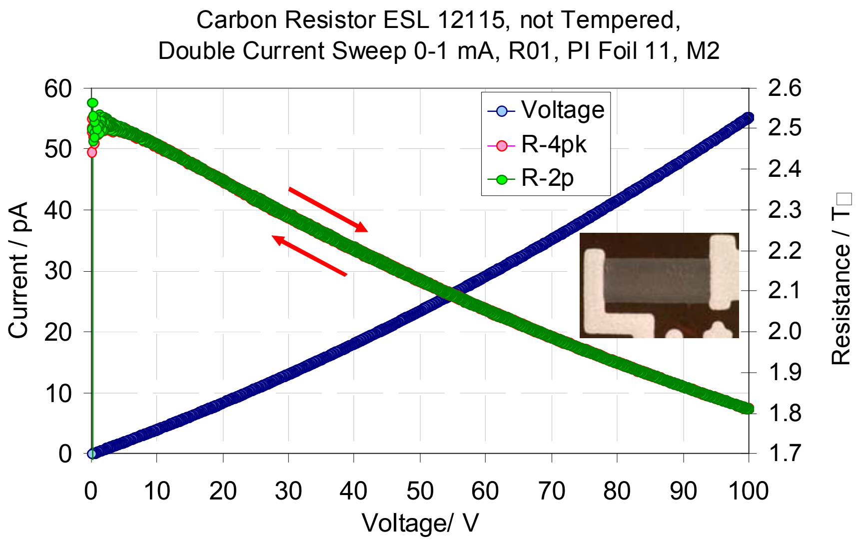
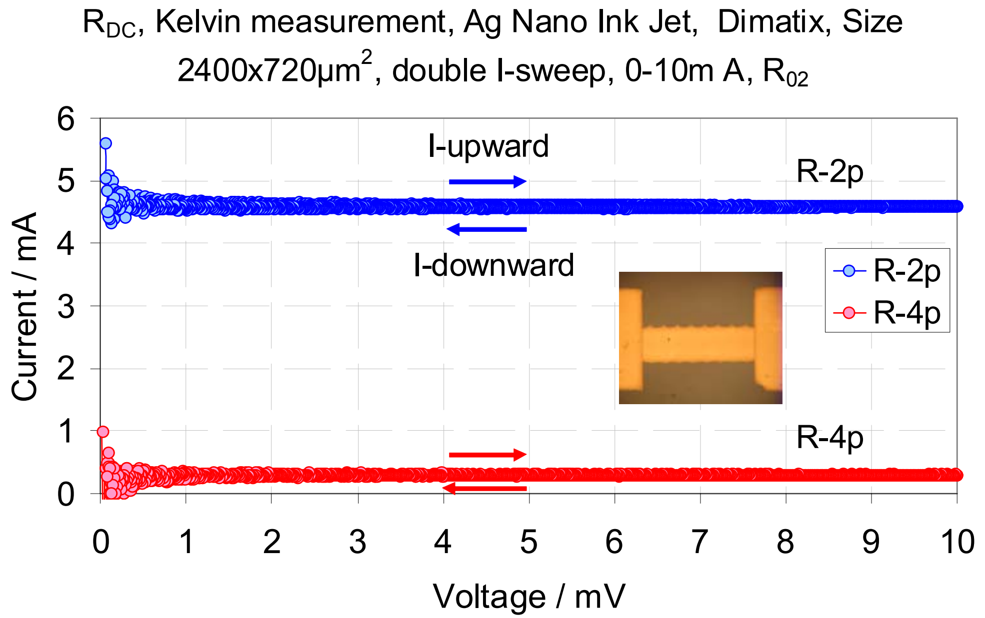
DC Electrical Stress and Measurement Modes





At high value resistances, no difference between 2P and 4P measurements is observed

For low value resistances, significant difference between 2P and 4P measurements (high $R_{contact}$). Example of ink- jet printed nano-silver layer.

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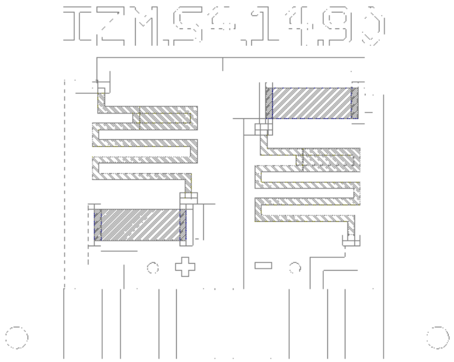
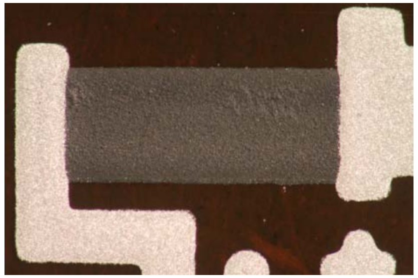
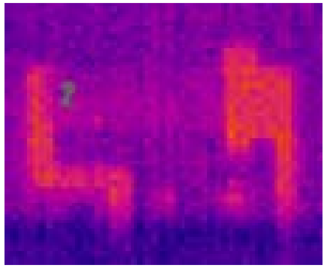
Polymer Carbon Based Resistors on PI

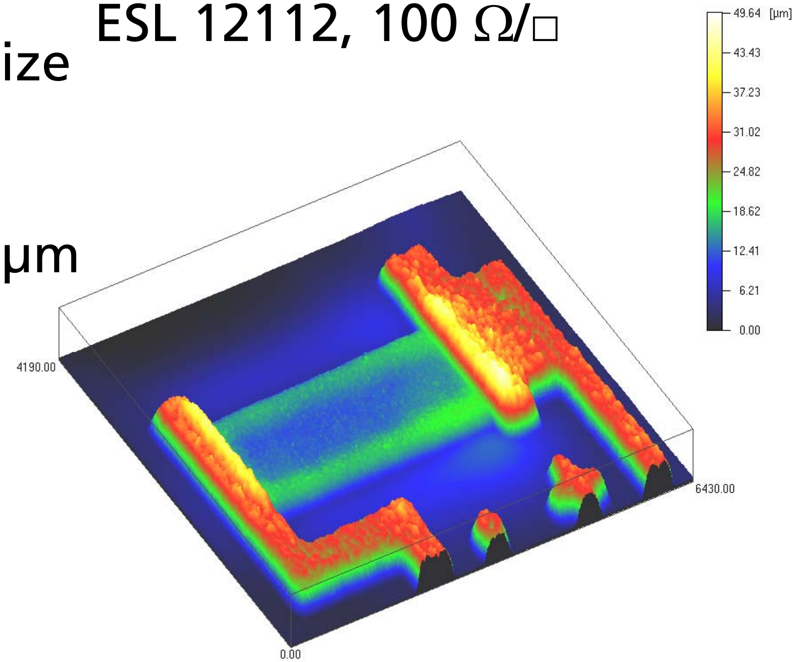


Layer size:
1.4x4mm printing size
1.4x3.55mm active area (2.5 □)
Layer thickness: 12 µm

Carbon-paste:
ESL 12112, 100 Ω/□





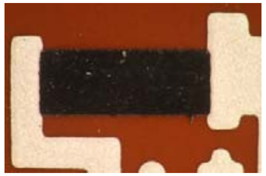


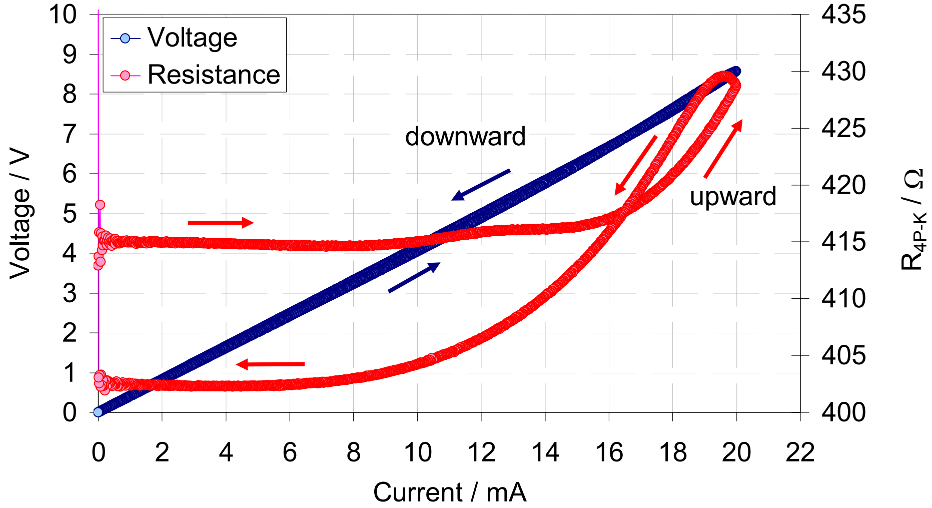
Optical view of carbon-based resistor on PI, 100 Ω/□

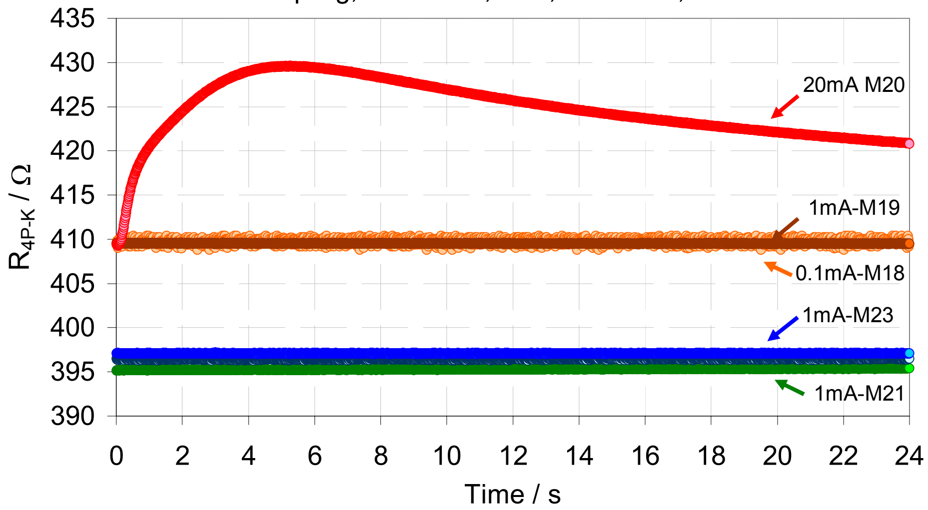
IR- Image: 26.5°C
DC- sampling at 100µA

3D scan of carbon-based resistor on PI, 100 Ω/□

DC- Stress on Flexible Thick Film Resistor



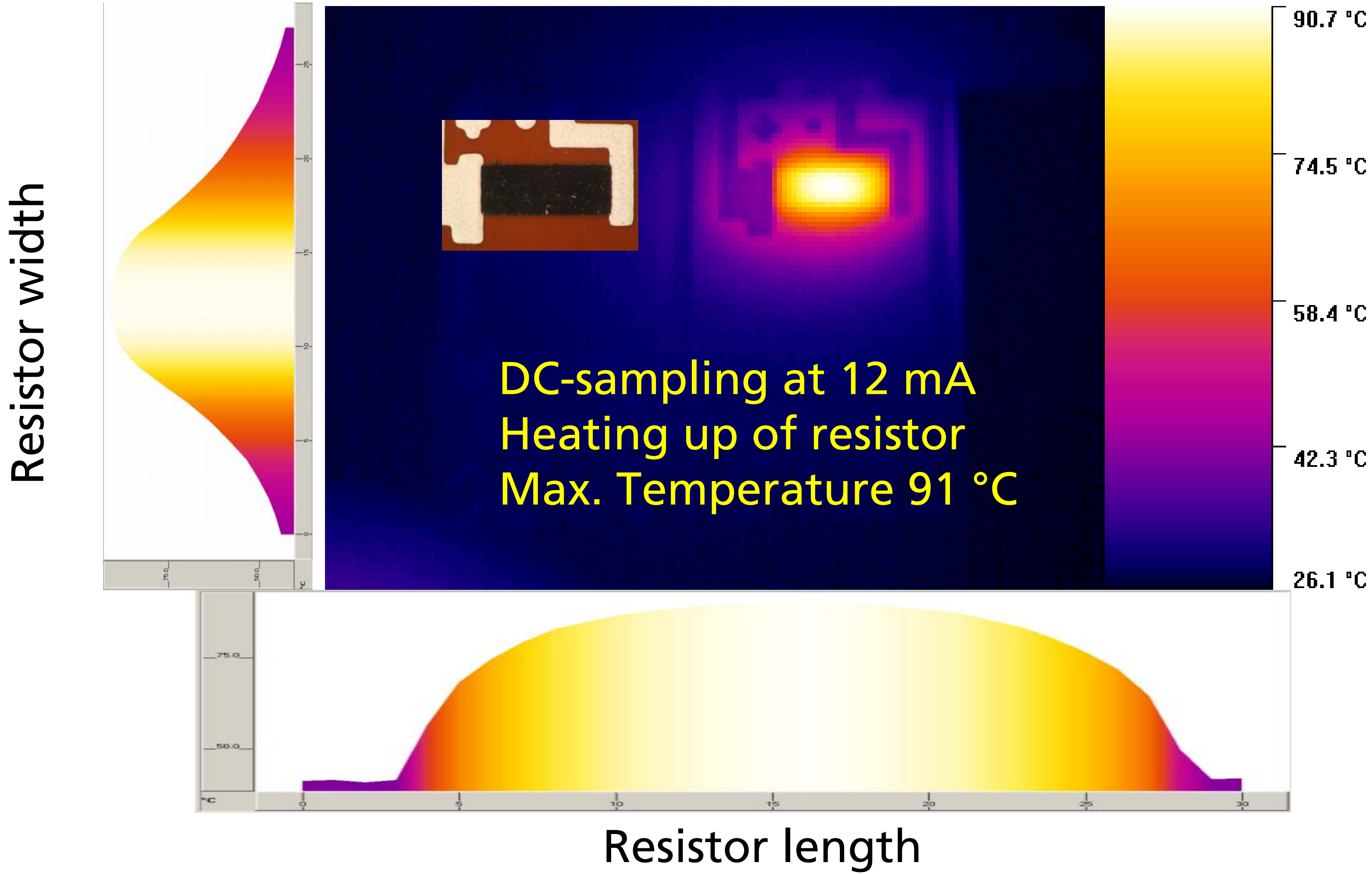




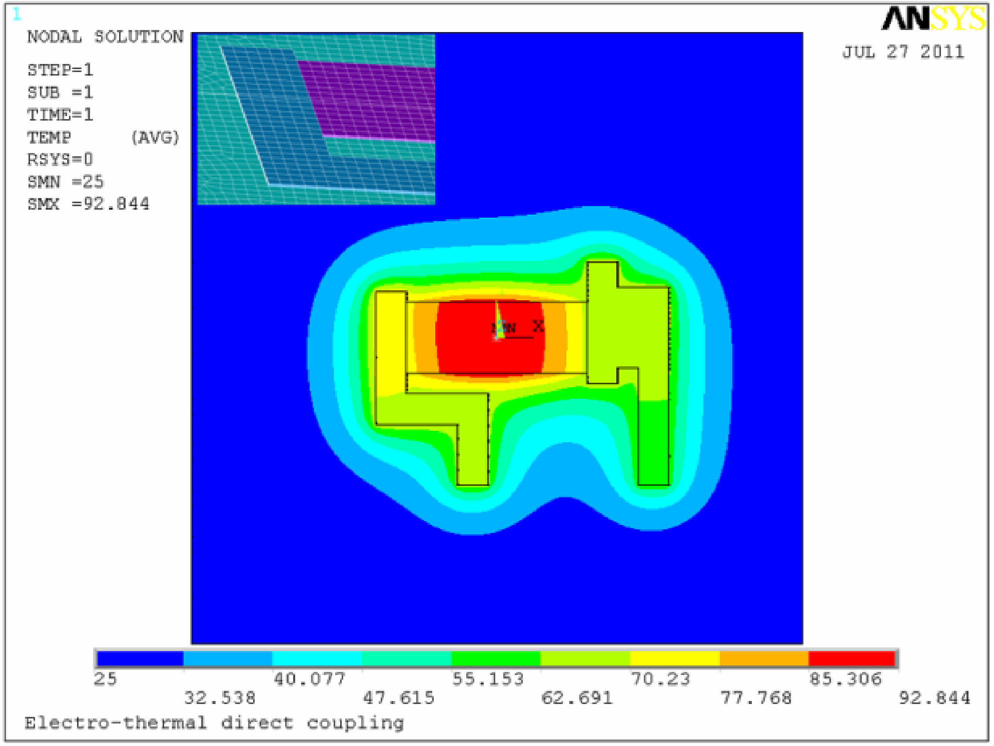
DC resistance during current sweep, thick film resistor on foil, 100 Ω/□ (permanent changes).

DC resistance during current sampling, thick film resistor on foil, 100 Ω/□ (permanent changes).

Temperature measurements, ESL 112 resistors on PI

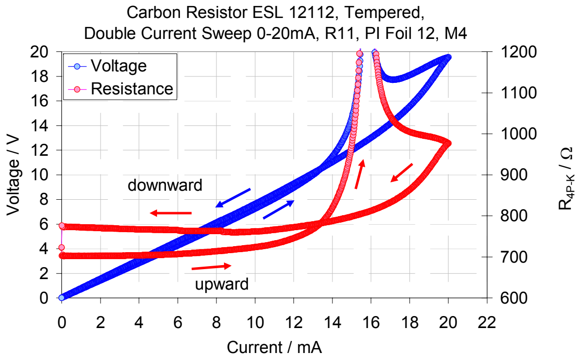


Temperature Distribution, ESL 112 resistors on PI

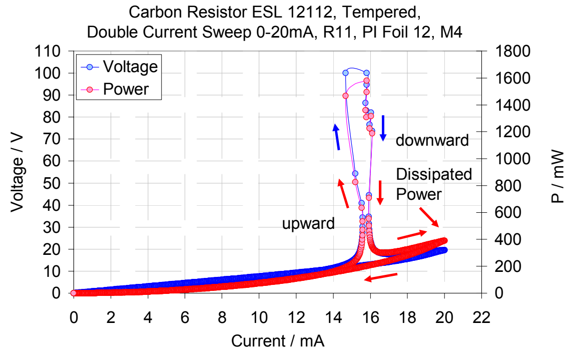


Simulation of temperature distribution during self- heating of flexible thick film polymer resistor on PI foil, showing hot spot in the center of the resistive layer.

DC- Stress on Flexible Thick Film Resistor



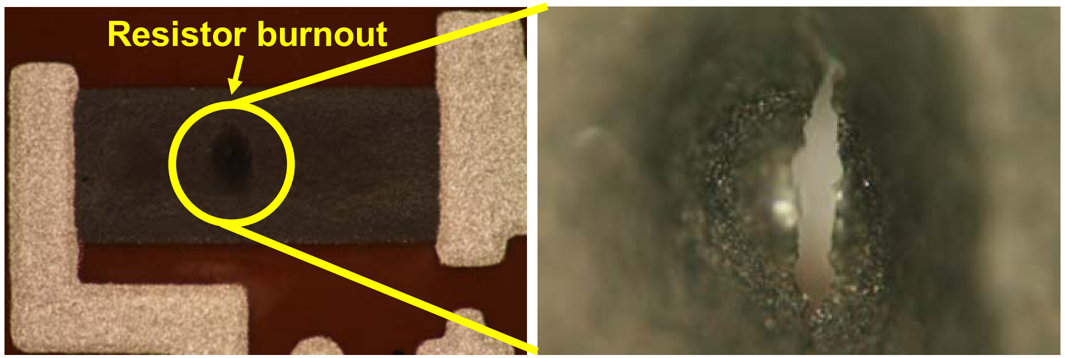
a)



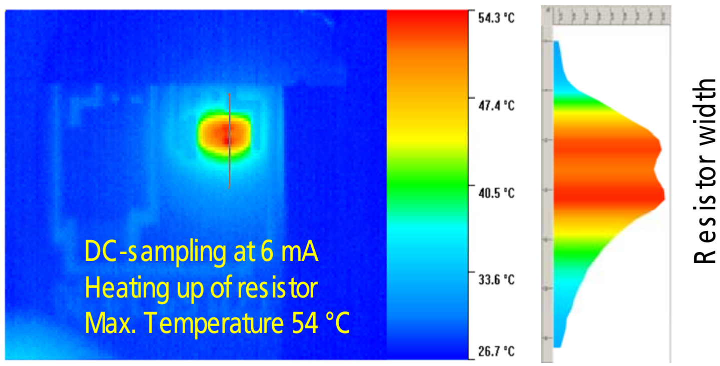
b)

power dissipation in resistive layer

power dissipation in resistive layer



a) b)



Resistor damage during DC stressing caused by hot spot in the center, generating two hot spots

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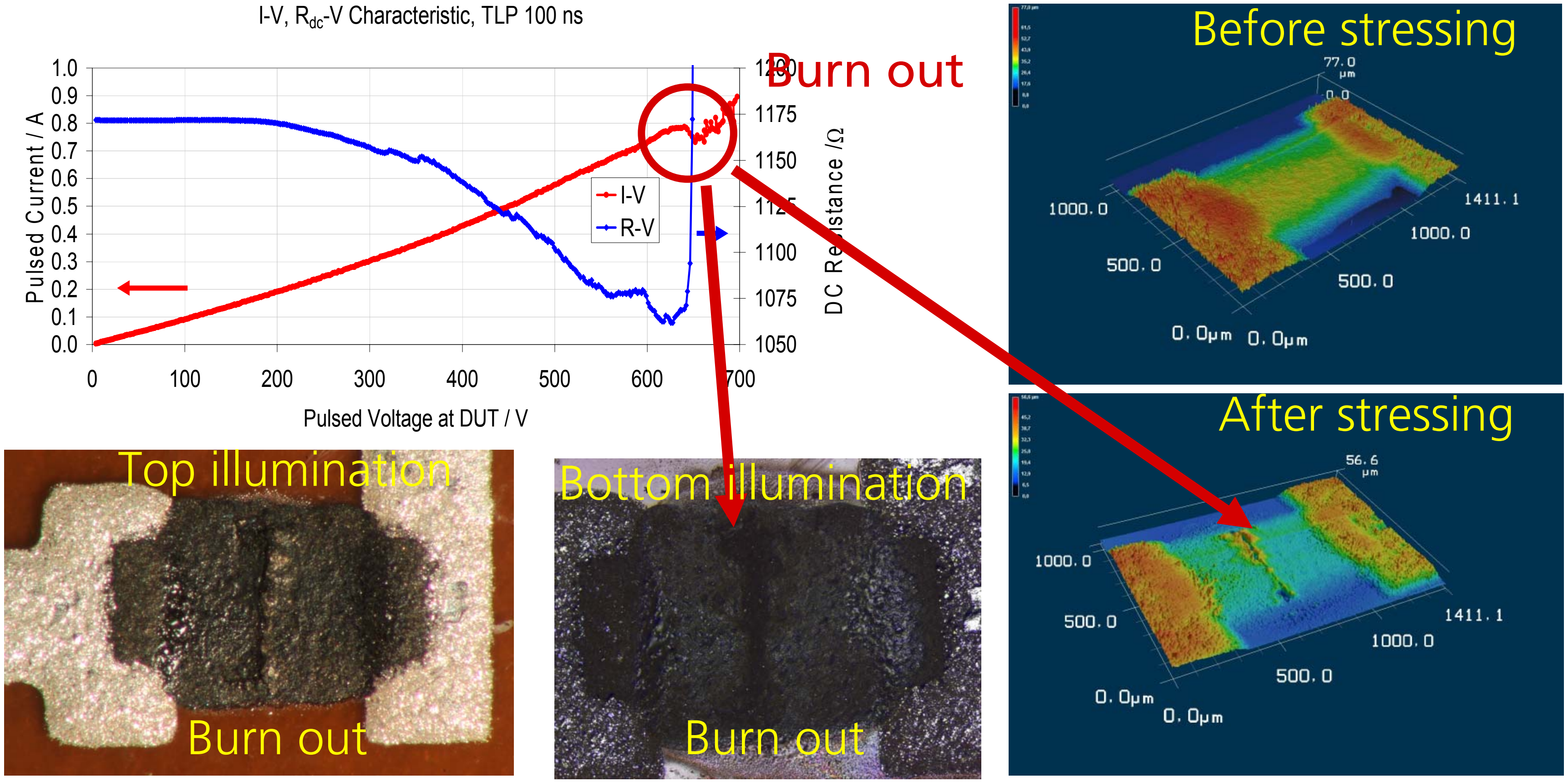
Damage Signature on Flexible Thick Film Resistors after Pulsed Stress



Resistor burn out after successive pulsing with increased voltage

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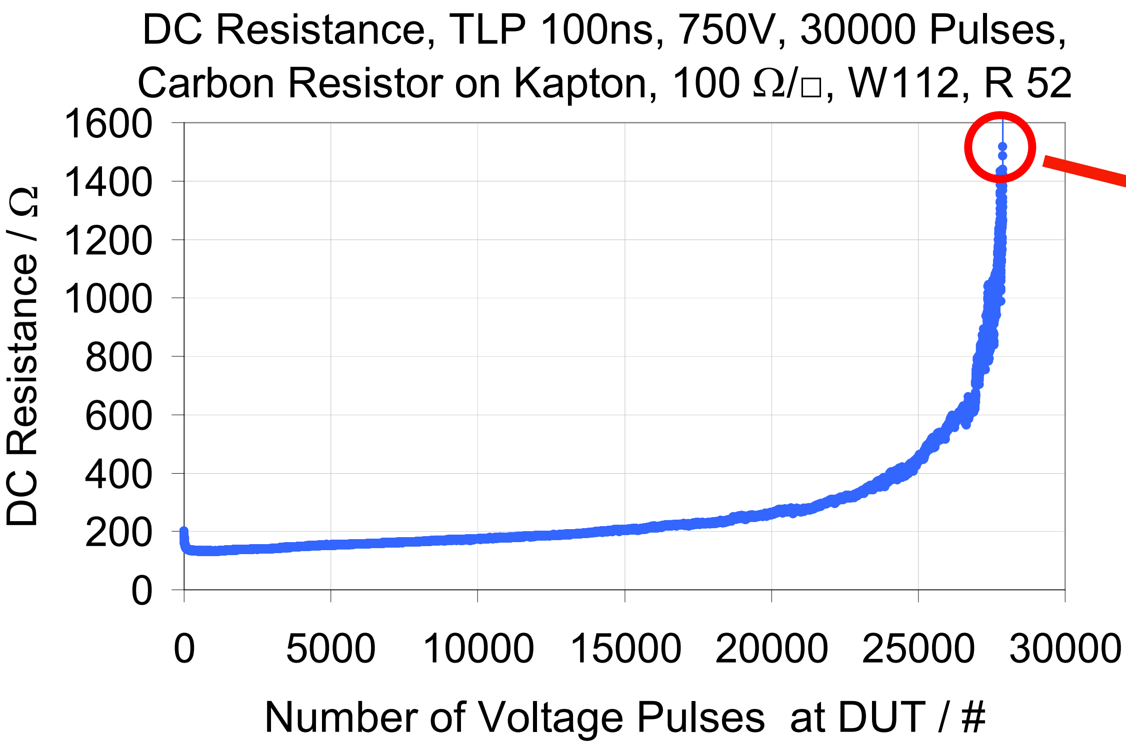
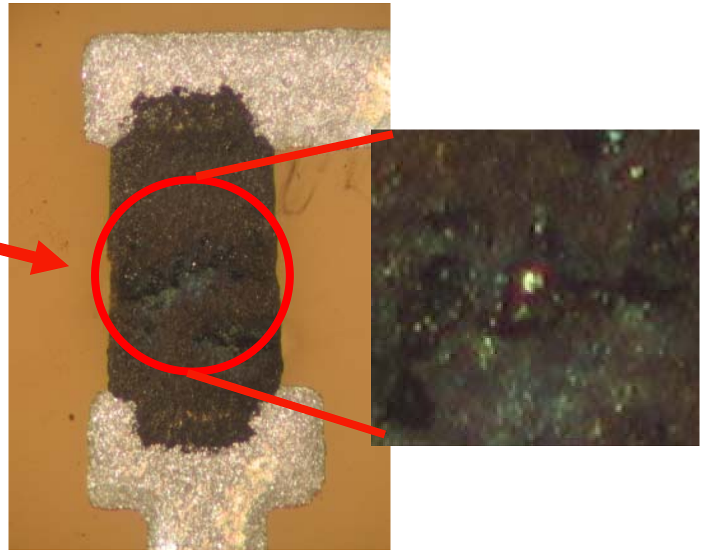
Pulsed Stress on Flex. Thick Film Polymer Resistor

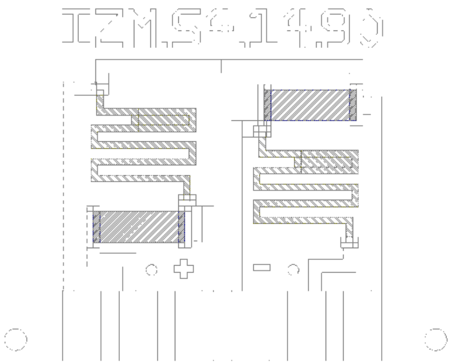




Resistor damage after 28000 applied pulses with constant voltage amplitude

DC-resistance change vs. nr. of applied pulses with constant voltage amplitude, TLP- voltage 750V, pulse width 100 ns, R 100 Ω/ □

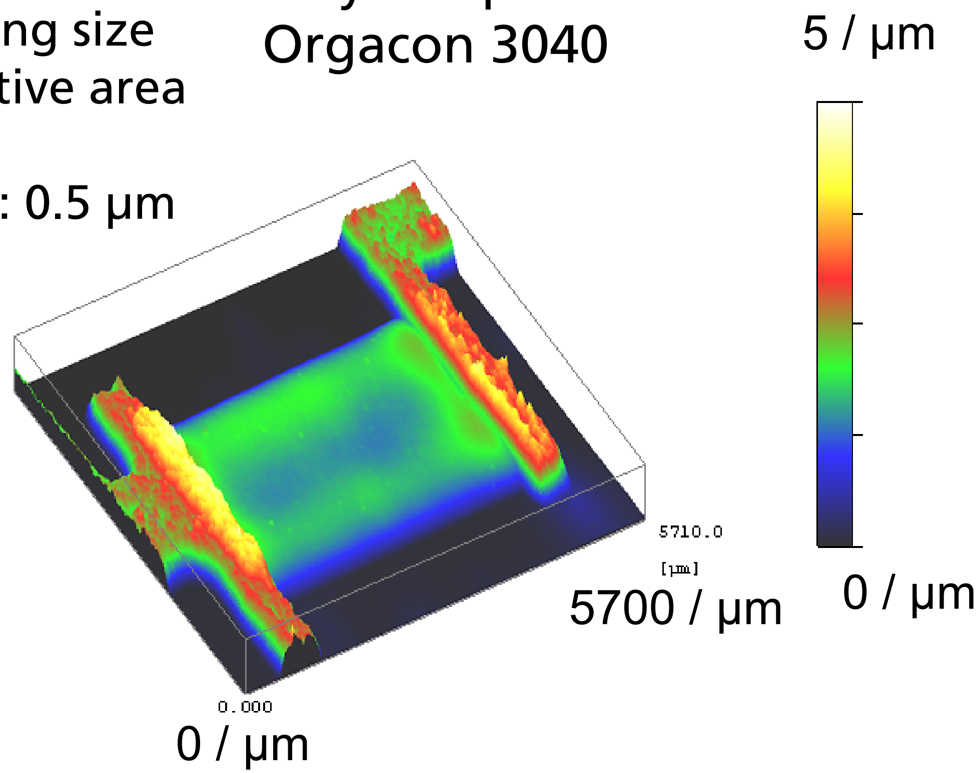
Polymer PEDOT:PSS Resistor on PET Foil



Layer size:
1.4x4mm printing size
1.4x3.55mm active area
(2.5 □)
Layer thickness: 0.5 µm

Polymer-paste:
Orgacon 3040

Optical view of PEDOT:PSS resistive layer on PET foil



3D scan of PEDOT:PSS resistive layer on PET foil

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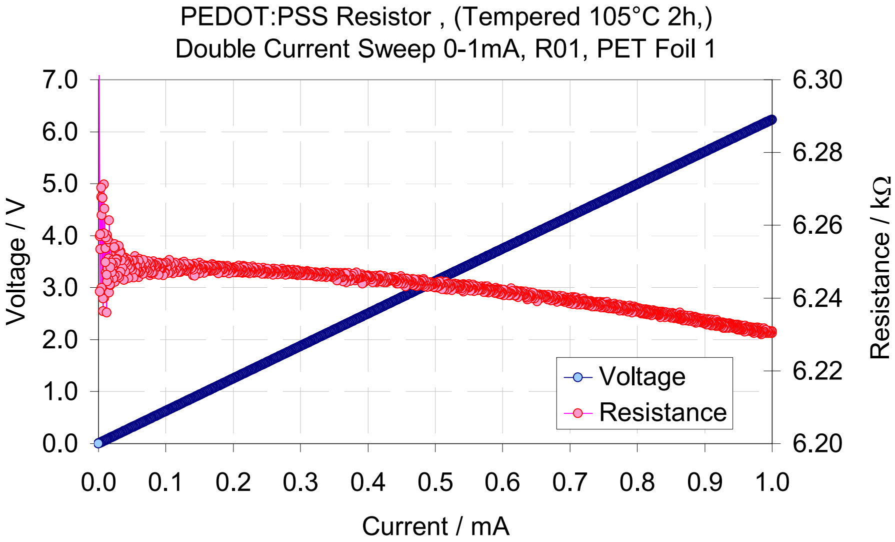
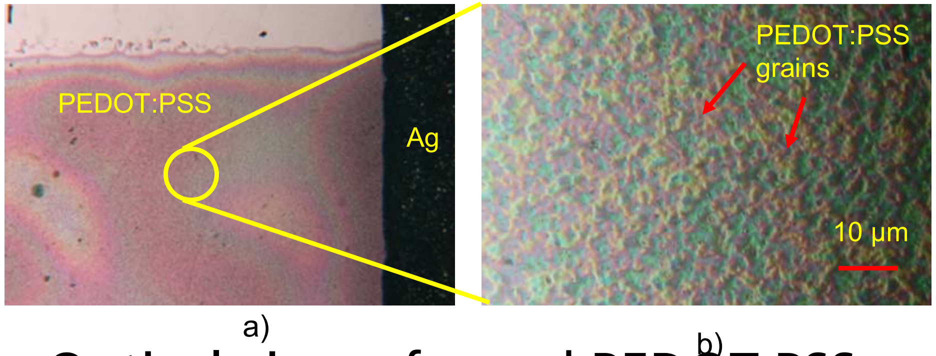
DC Electrical Sweep Measurement of PEDOT:PSS

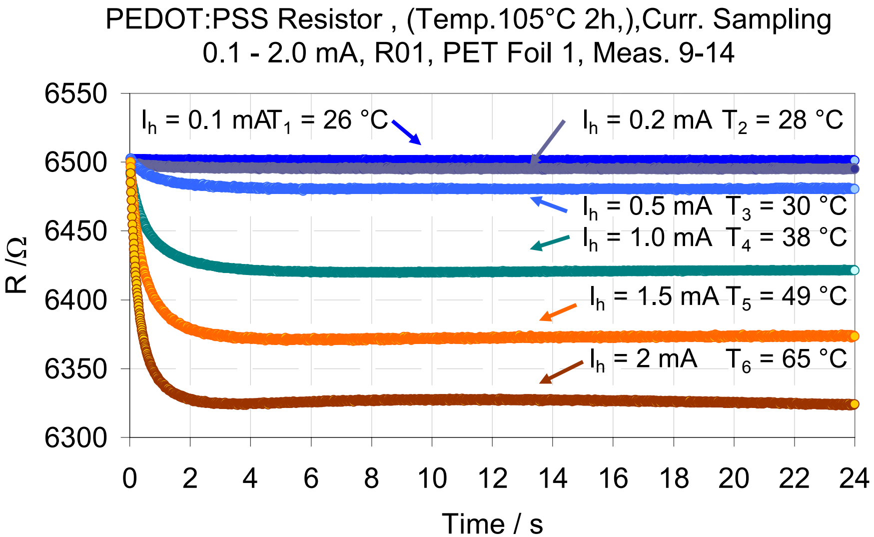


DC resistance during current sweep, PEDOT:PSS resistive layer on PET foil, Rs 2.5 kΩ/□ (reversible changes).

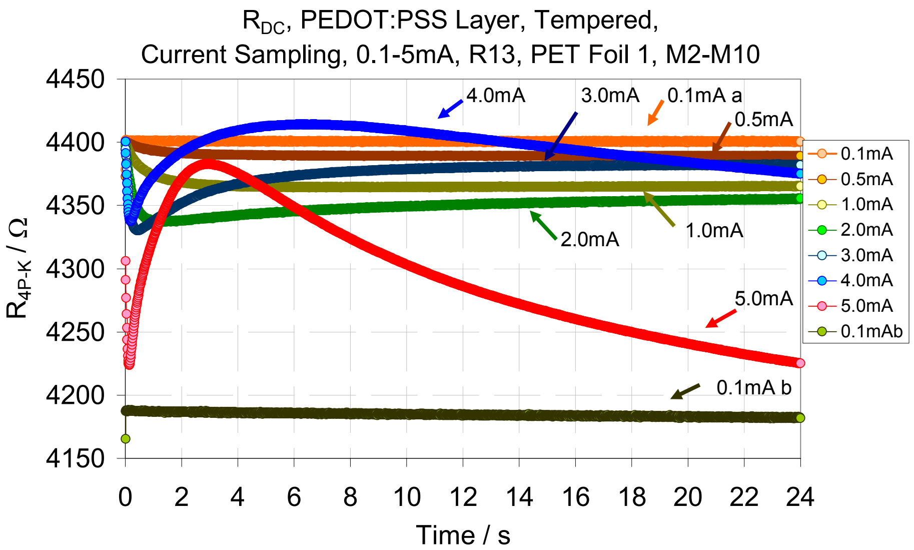


Optical view of cured PEDOT:PSS polymer paste, Orgacon 3040, a) resistive layer with polymer conductor (silver), b) zoomed resistive layer showing PEDOT:PSS grains.

DC Electrical Sweep Measurement of PEDOT:PSS



a)



b)

DC resistance during current sampling, PEDOT:PSS resistive layer on PET foil, a) reversible changes, b) irreversible changes.

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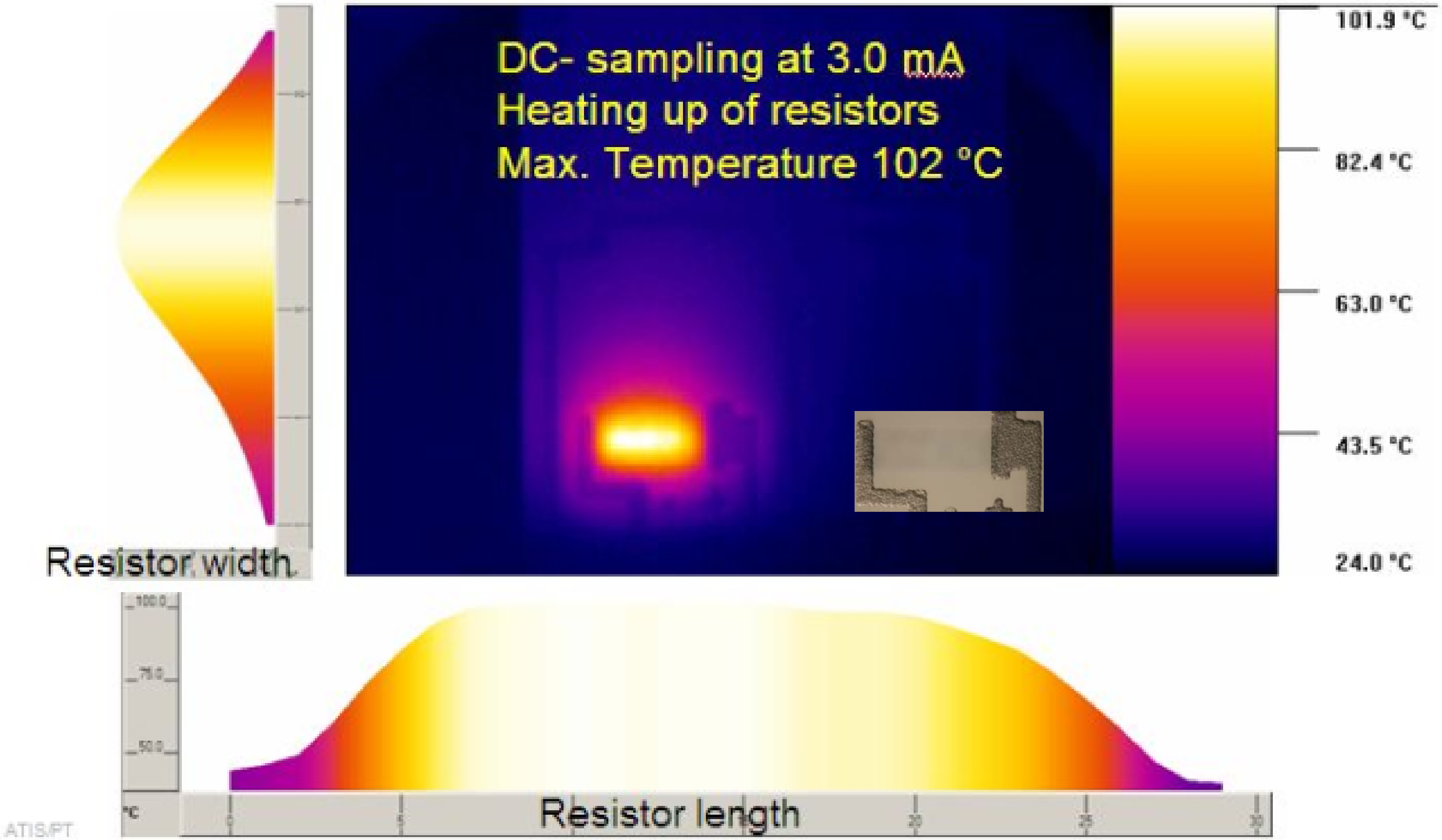
Temperature Profile of PEDOT:PSS



Temperature distribution during self- heating of PEDOT:PSS resistive layer on PET foil, hot spot in the center of the resistive layer.

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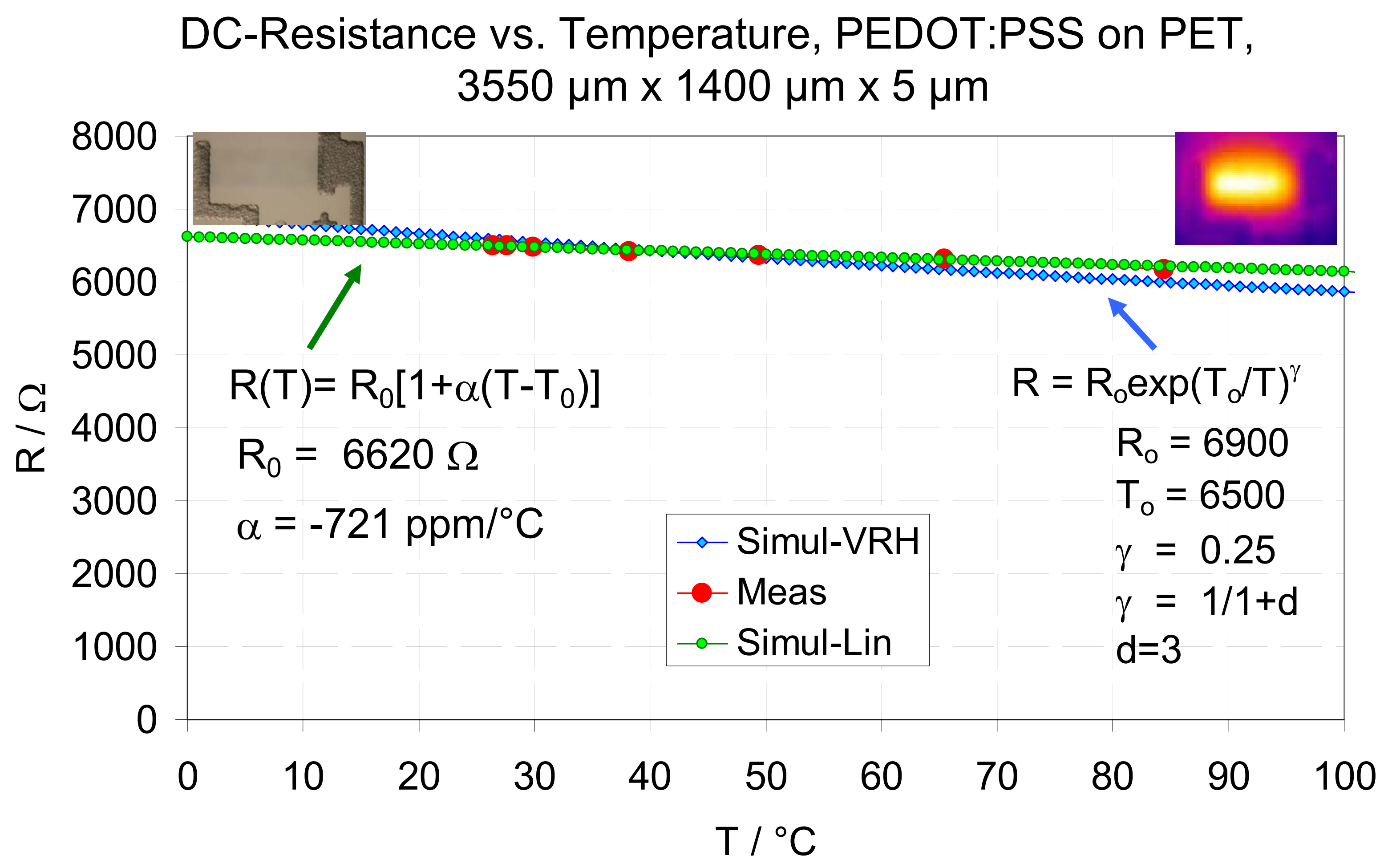
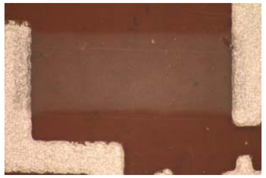
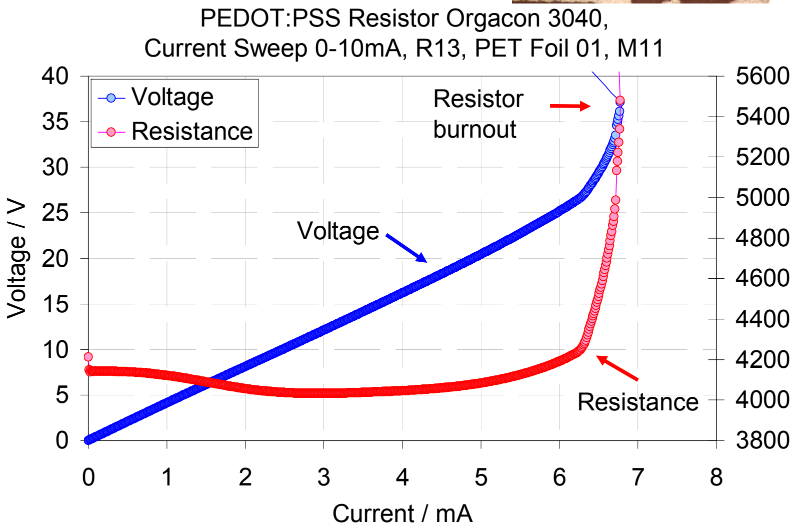
DC Resistance versus Temperature

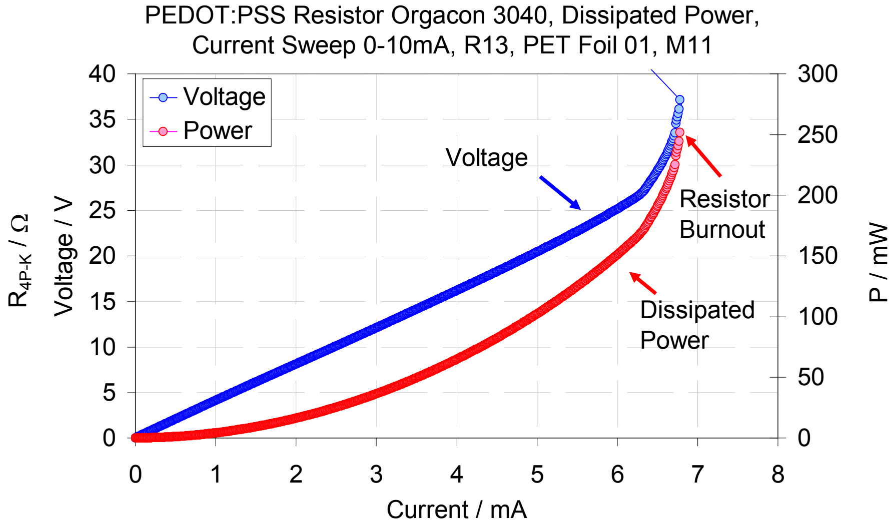


DC Electrical Stress on PEDOT:PSS layer





a)



b)

DC resistance during current sweep, layer burnout.

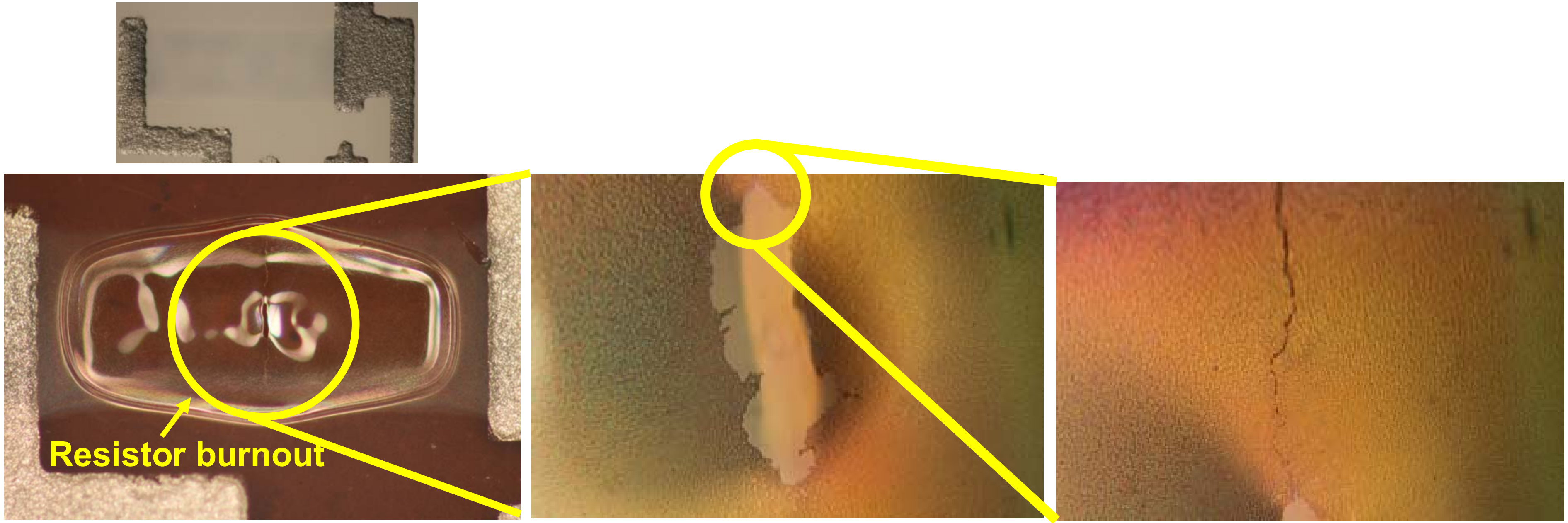
Current density at burnout:

1 kA/cm^2

DC-power during current sweep, layer burnout,

Dissipated power at burnout: 250 mW

Layer Burnout after DC Electrical Stress



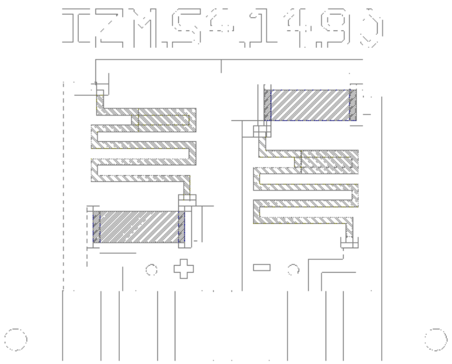
a) b) c)

a) Resistor burnout during DC stressing,

b) caused by hot spot in the center of the flexible polymer PEDOT:PSS resistor on PET foil,

c) crack propagation through resistive layer

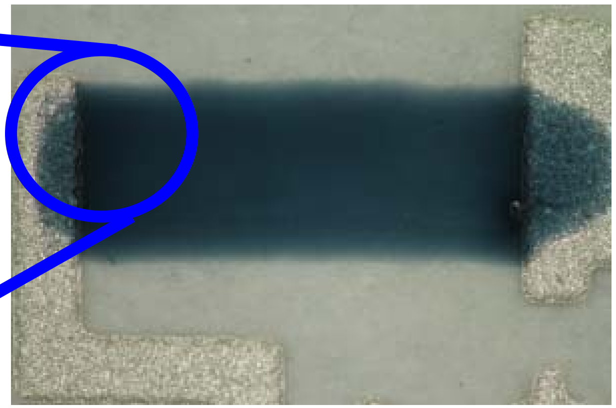
Polymer PEDOT:PSS Resistor on PET Foil



Layer size:
1.4x4mm printing size
1.4x3.55mm active area
(2.5 □)
Layer thickness: 1 µm

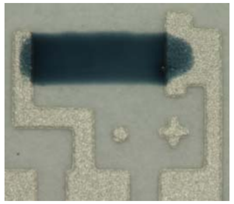
Polymer-paste:
Clevios PH1000 EG

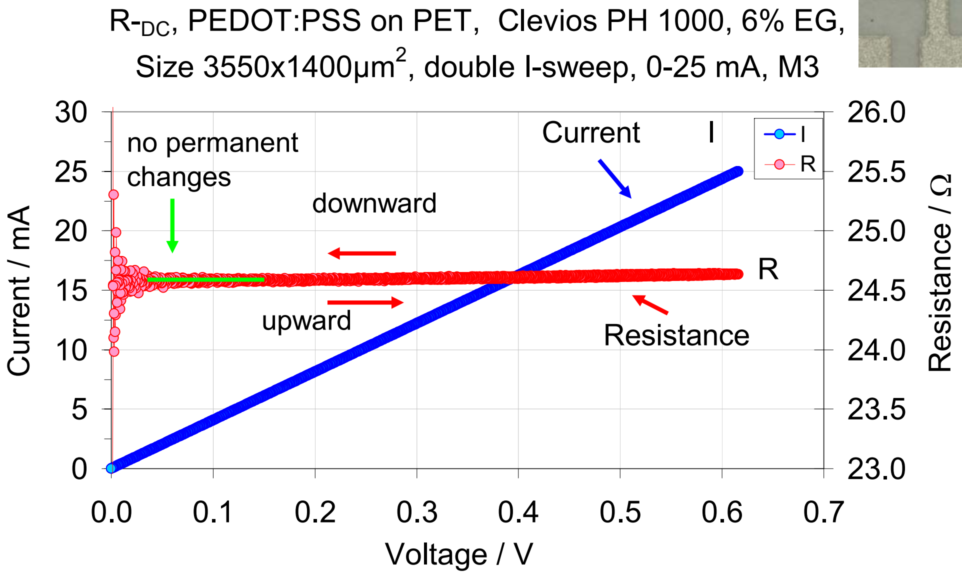
Zoomed optical view of PEDOT:PSS resistive layer on PET foil

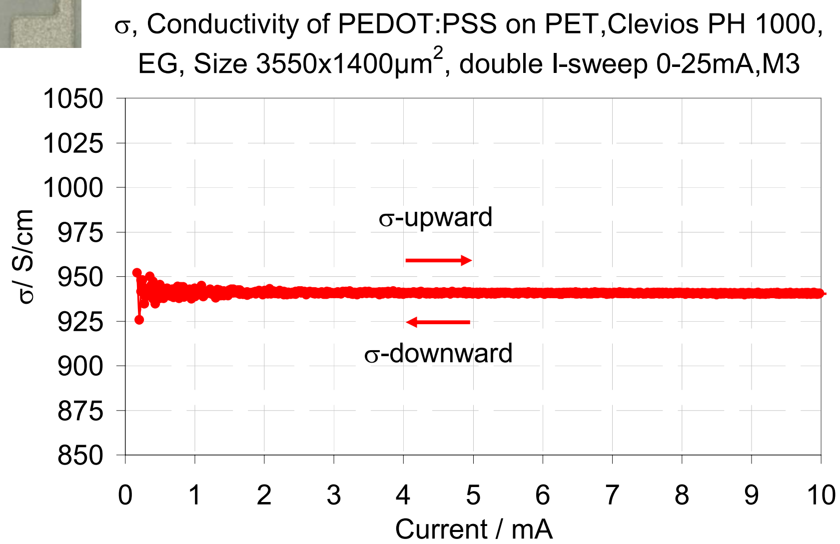


Optical view of PEDOT:PSS resistive layer on PET foil

DC Electrical Sweep Measurement of PEDOT:PSS







DC- resistance during current sweep, 0-25mA

DC- conductivity during current sweep, 0-10mA

Recommended current density, max: 50 A/cm²

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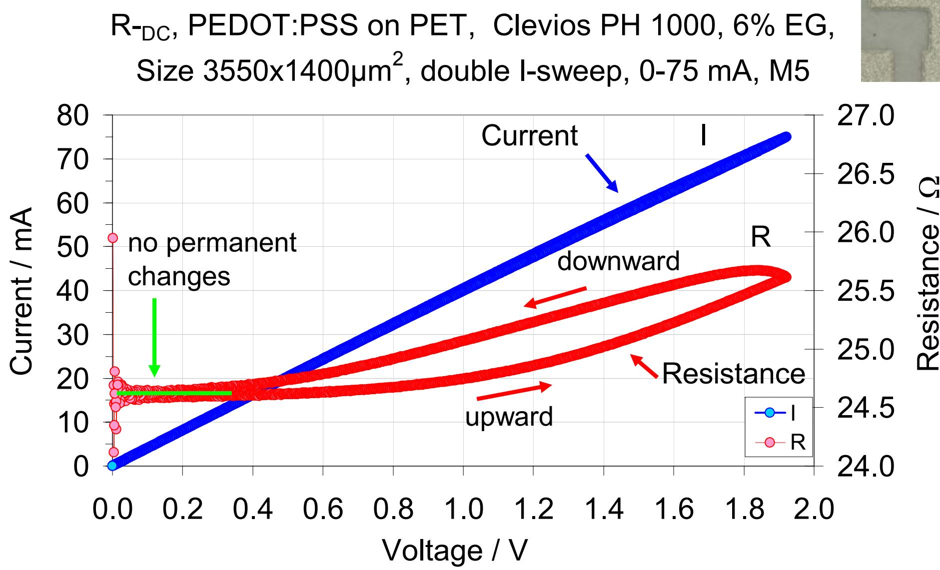
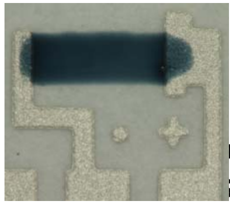
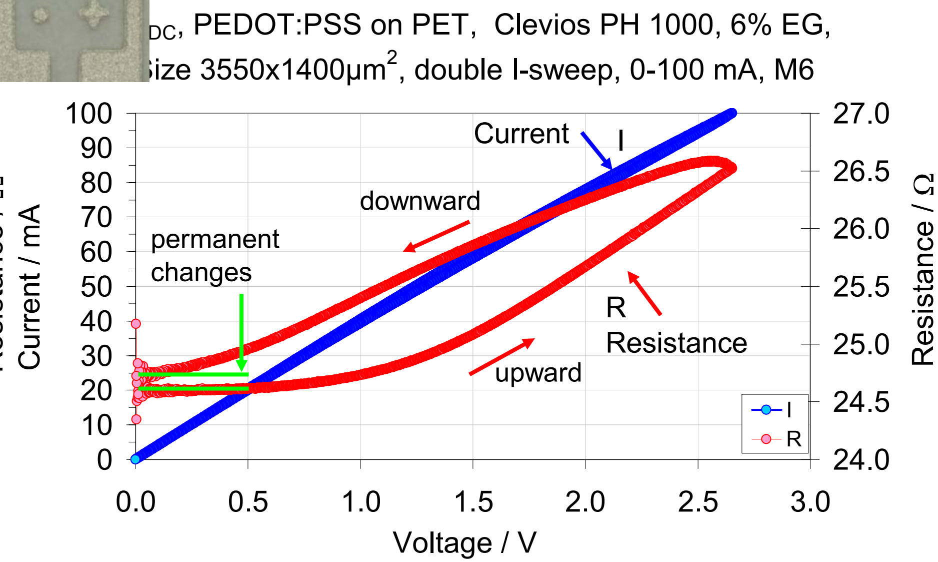
DC Electrical Sweep Measurement of PEDOT:PSS



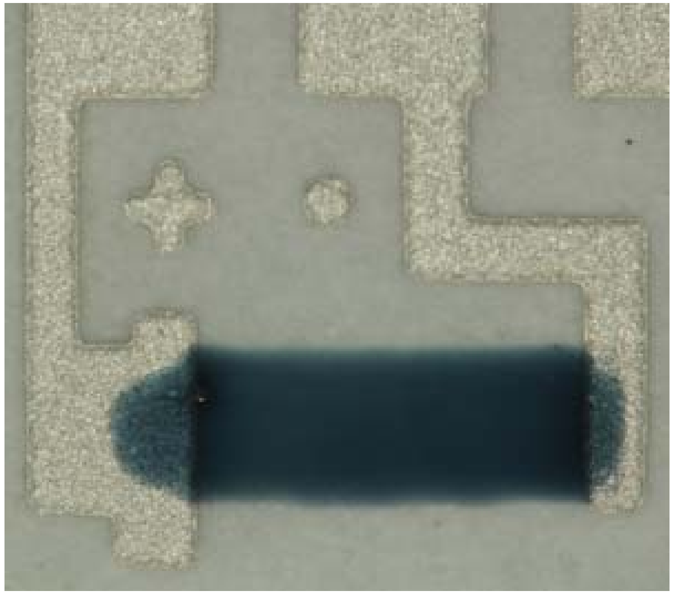


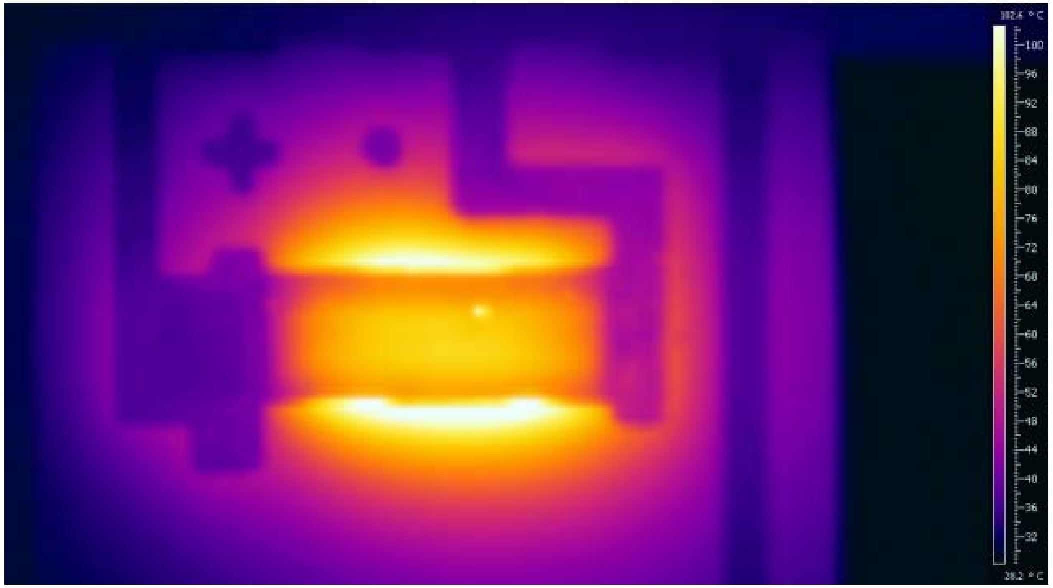


DC- resistance during current sweep, 0-75mA, no permanent changes

DC- resistance during current sweep, 0-100mA, permanent changes

Temperature Distribution During Self Heating

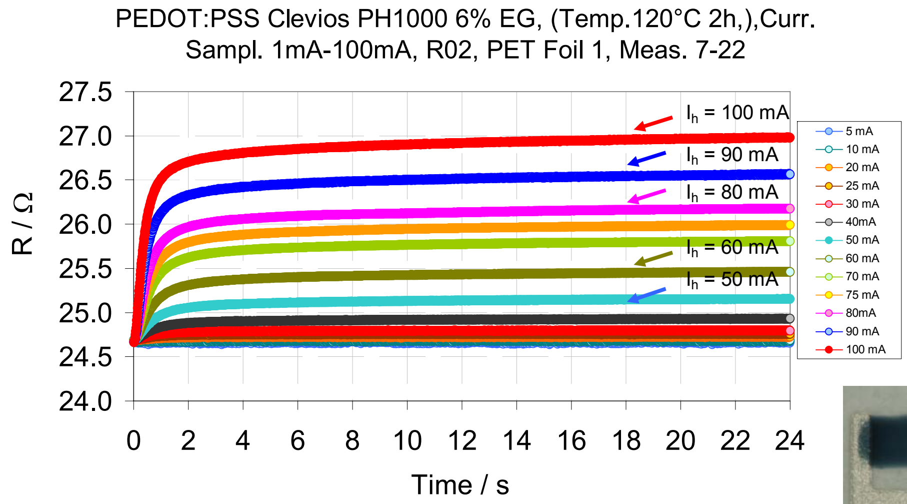


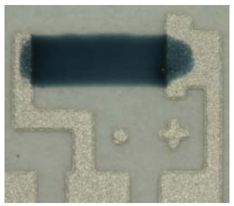


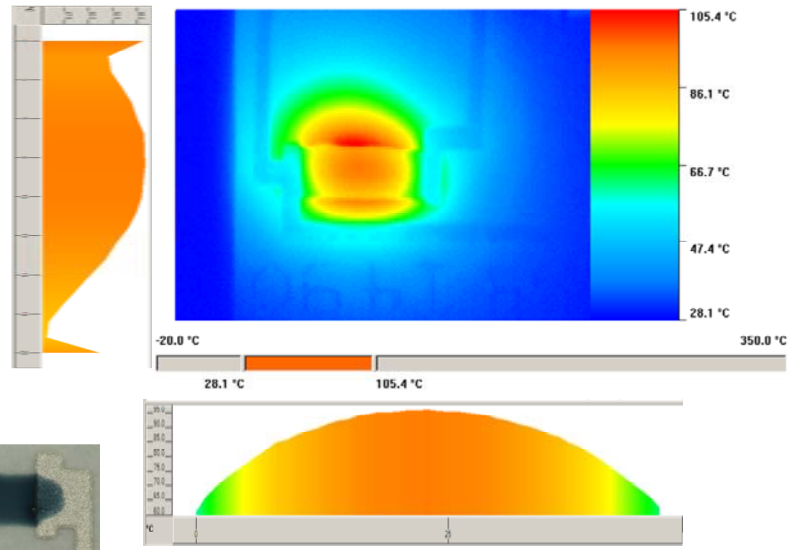
Optical image of PEDOT:PSS layer before current stressing

IR image and temperature measurement during current sampling at 100mA

DC Electrical Sampling Measurement on PEDOT:PSS



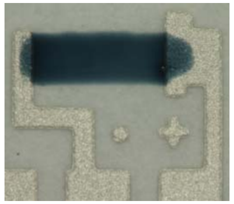


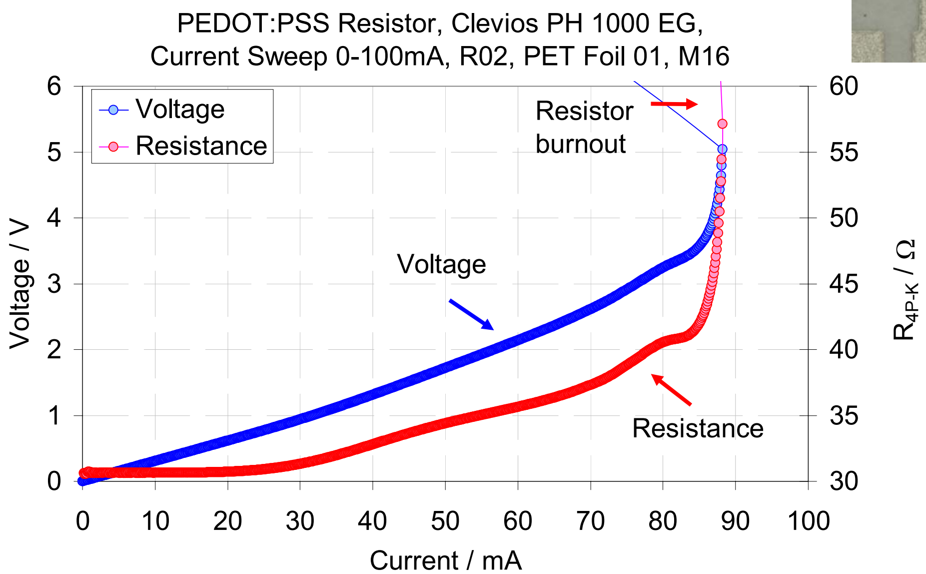


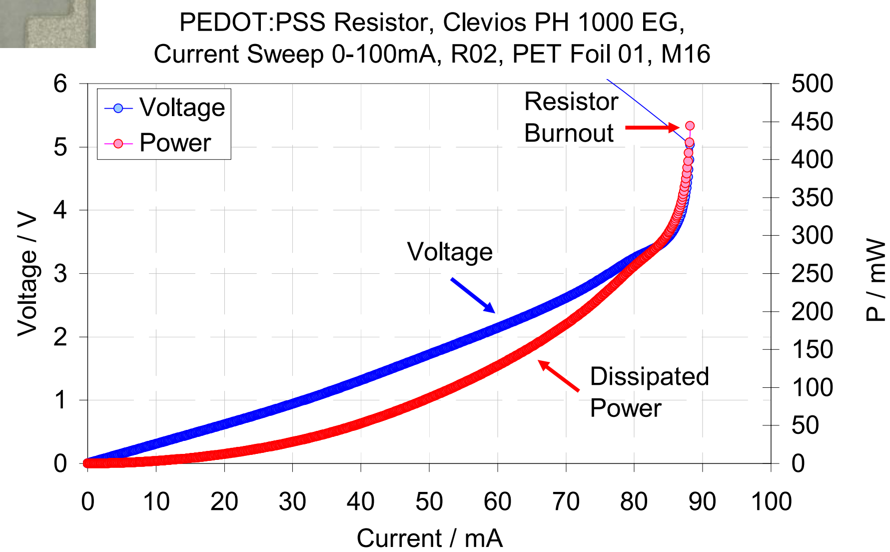
DC- resistance during multiple current samplings, 1-100mA

Layer temperature distribution during current sampling with 100mA

DC Electrical Stress on PEDOT:PSS layer







DC resistance during current sweep, layer burnout.

Current density at burnout:

7 kA/cm²

DC-power during current sweep, layer burnout,

Dissipated power at burnout: 450 mW

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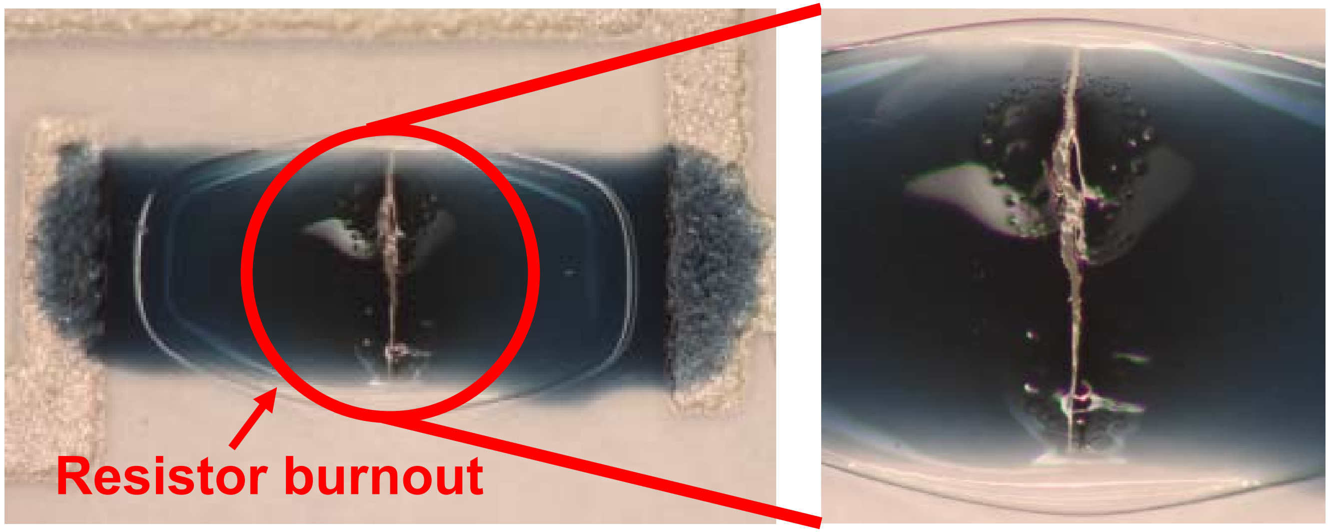
Layer Burnout after DC Electrical Stress



Layer burn- out during current sweep

DC Resistance versus Temperature

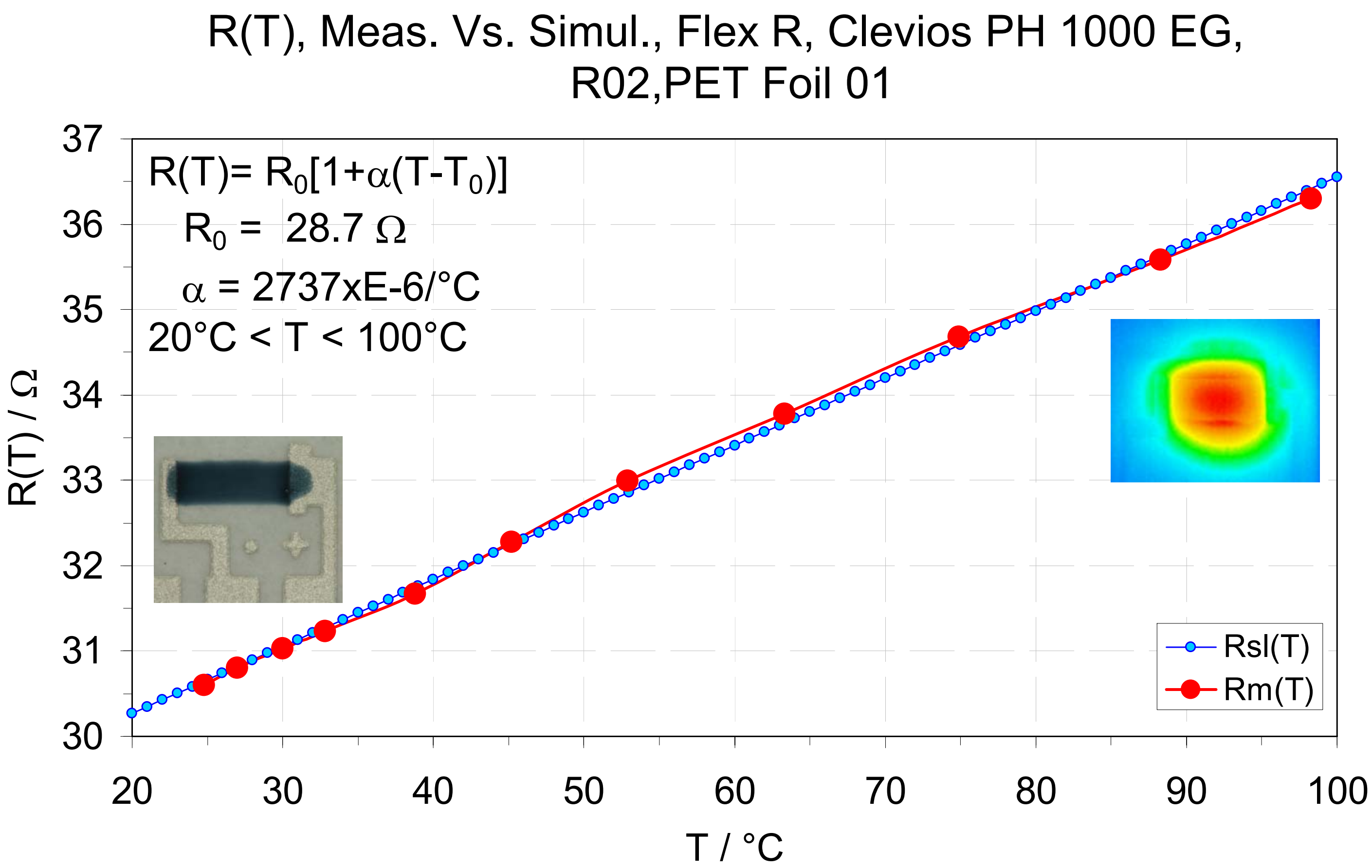
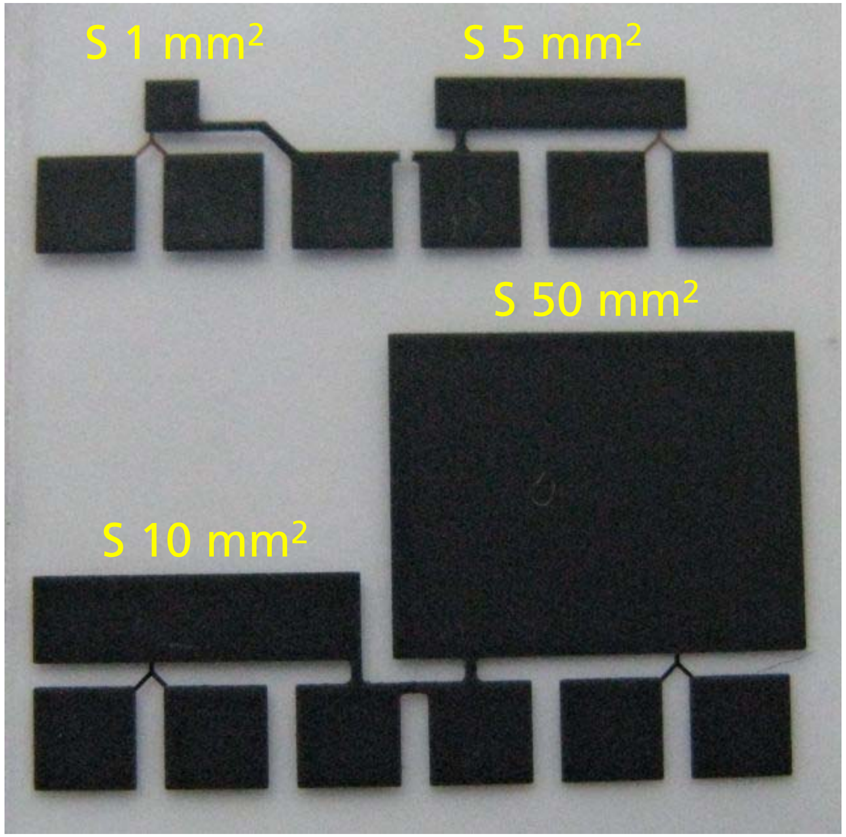


Plate Capacitor (Copper- PVP- Carbon) on PEN



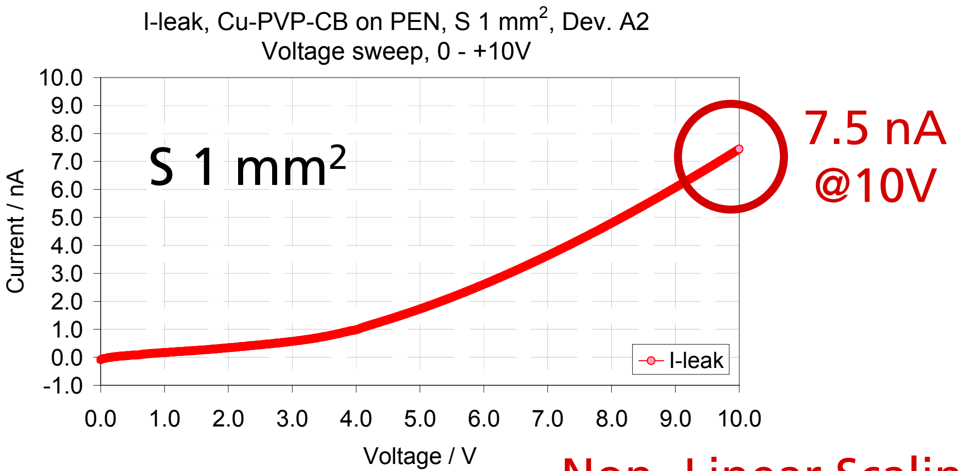
Optical view

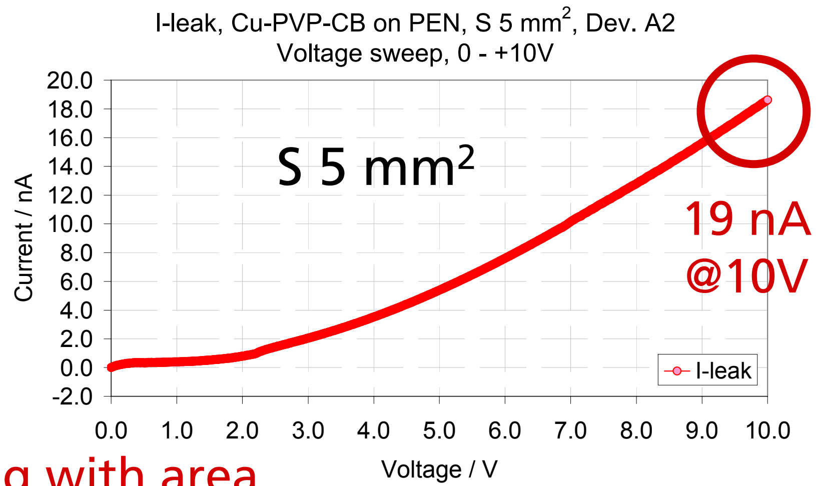
Structure:
- Bottom electrode: Copper
-Top electrode: polymer carbon
-Dielectric: PVP, 1.5 µm thick
  - ε_r : 6.4 (measured)

-C_{calc}: 37.8 pF/mm²

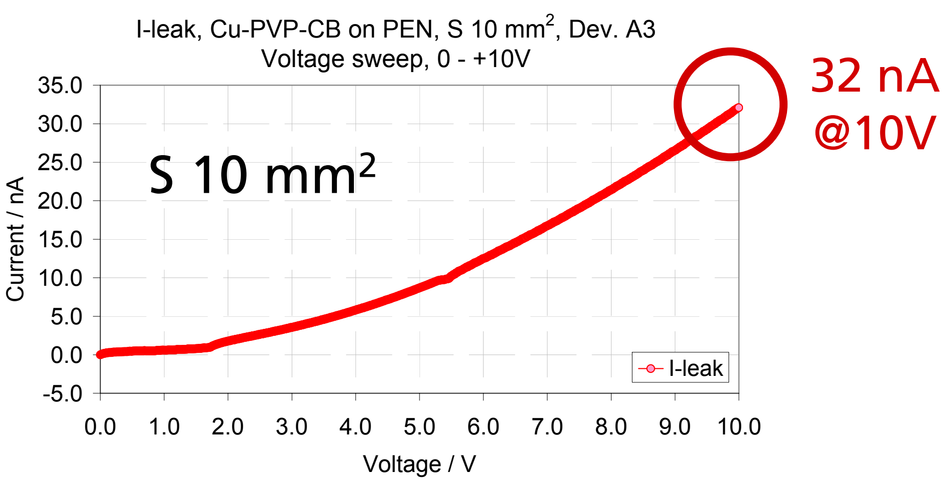
-Electrode areas S:
- 1 mm²
- 5 mm²
- 10 mm²
- 50 mm²

Plate Capacitor (Copper- PVP- Carbon) on PEN





Non- Linear Scaling with area



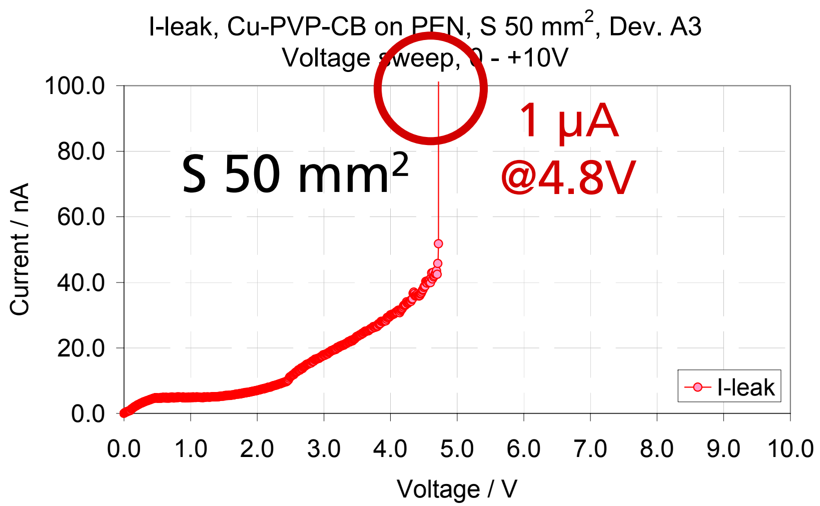
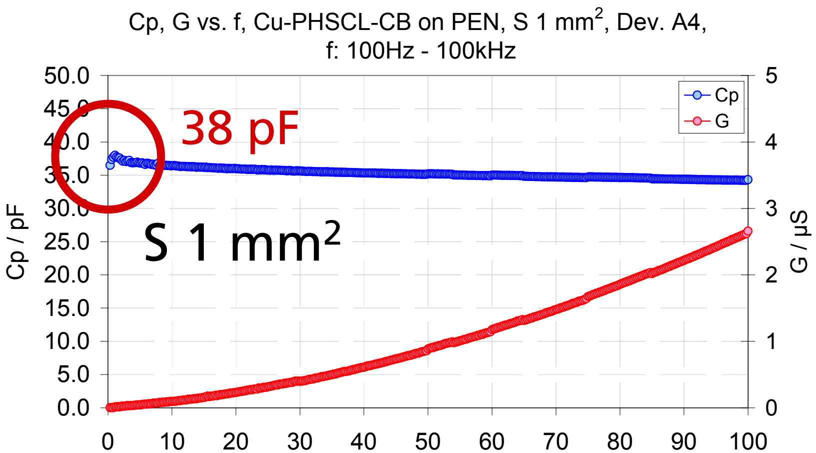
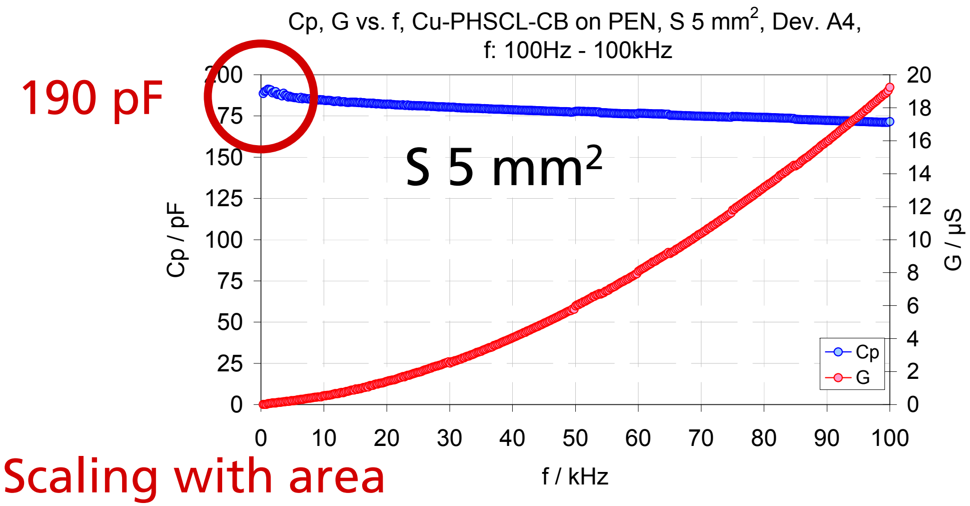


Plate Capacitor (Copper- PVP- Carbon) on PEN





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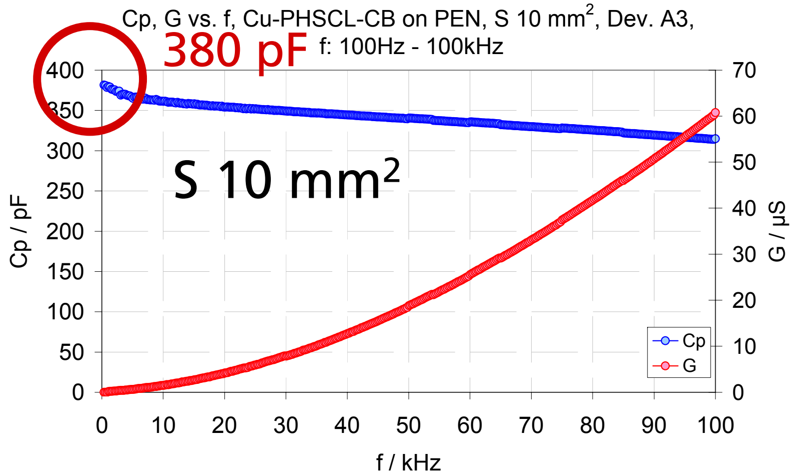

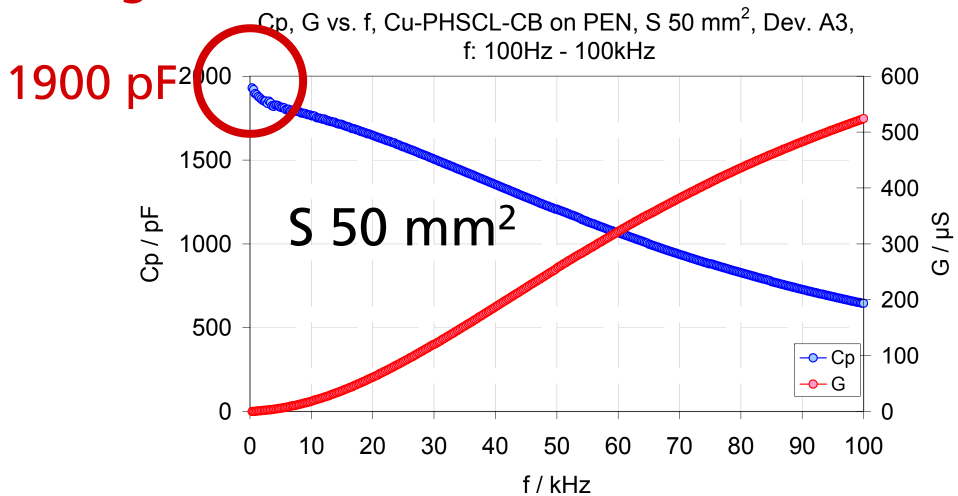

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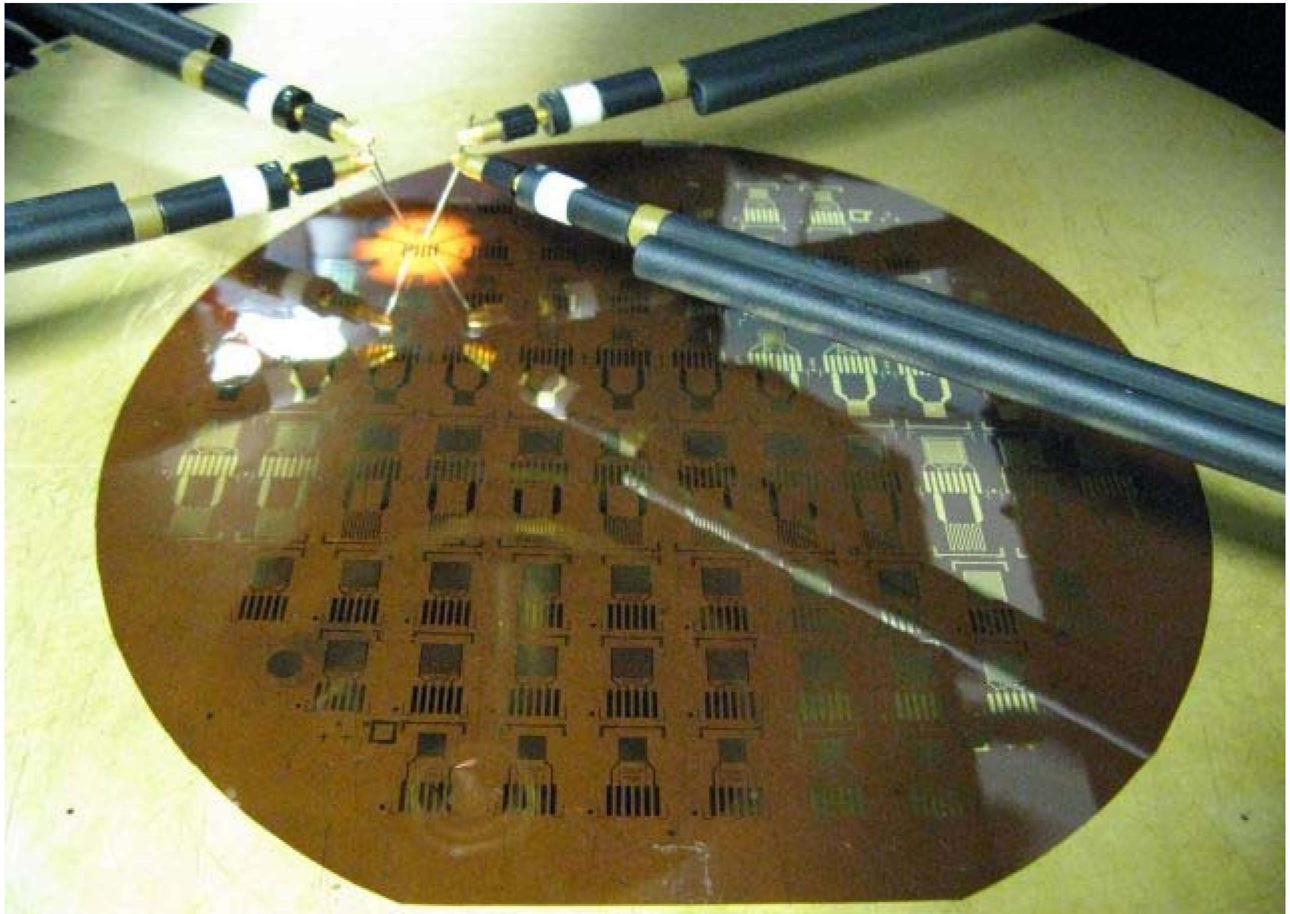
El. Meas. of Thin Film Passive Devices on PI Foil



Test setup for electrical measurements of thin film passive devices on PI foil, Wafer Prober Süss PA 300

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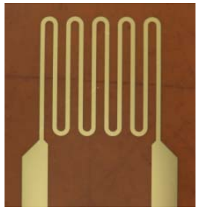
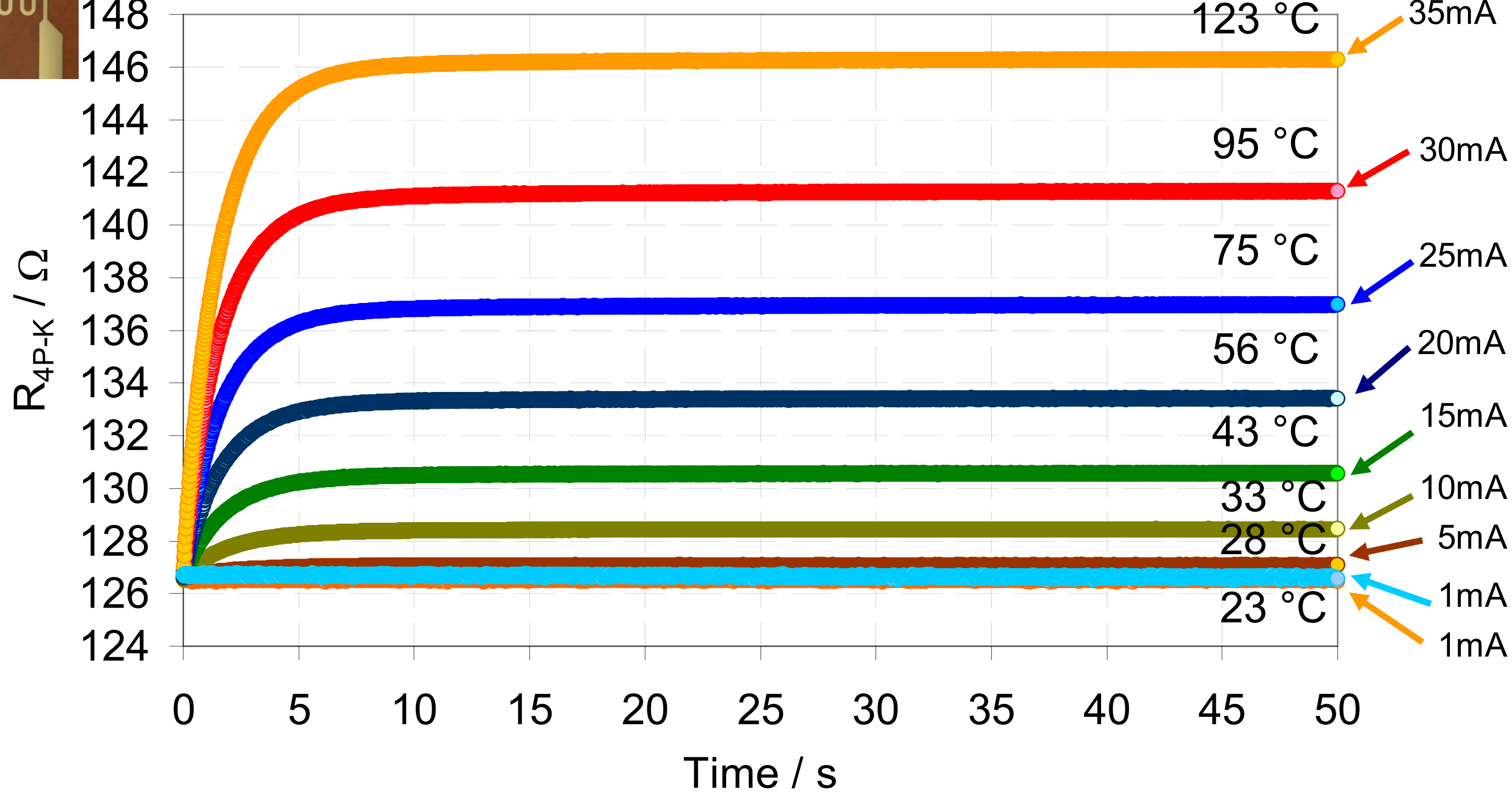
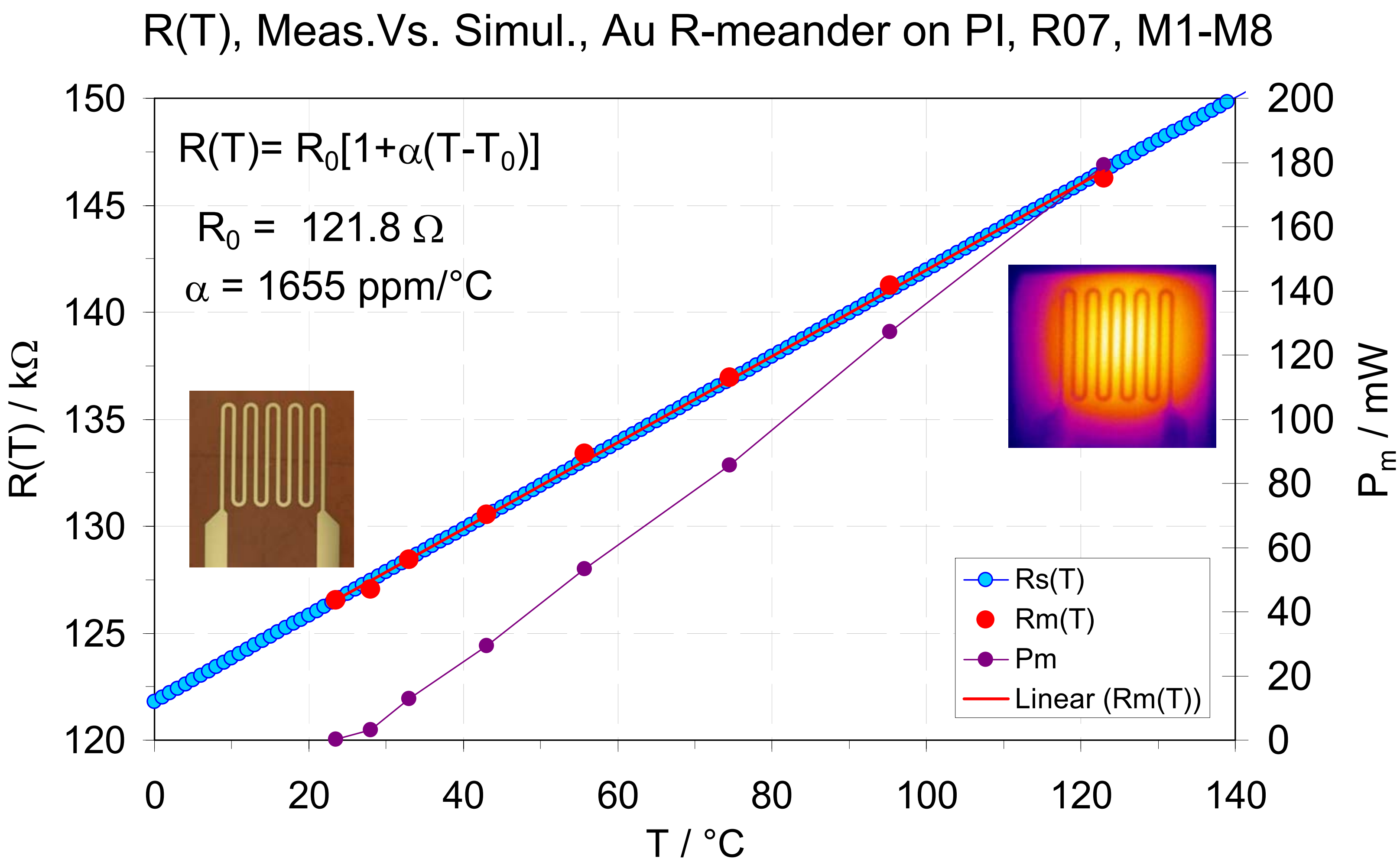
El. Meas. of Thin Film Meander Resistor on PI

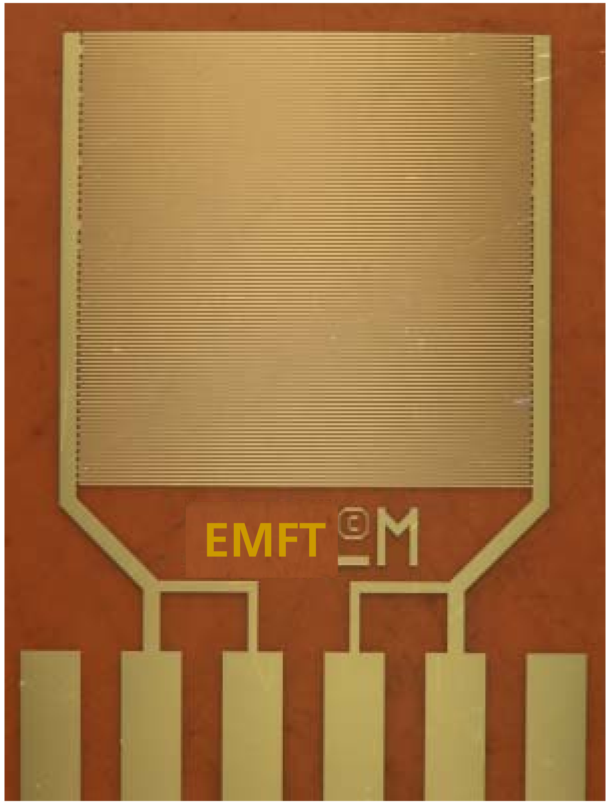




TCR of Thin Film Meander Resistor on PI- Foil



Interdigital Capacitor on PI- Foil



Optical view

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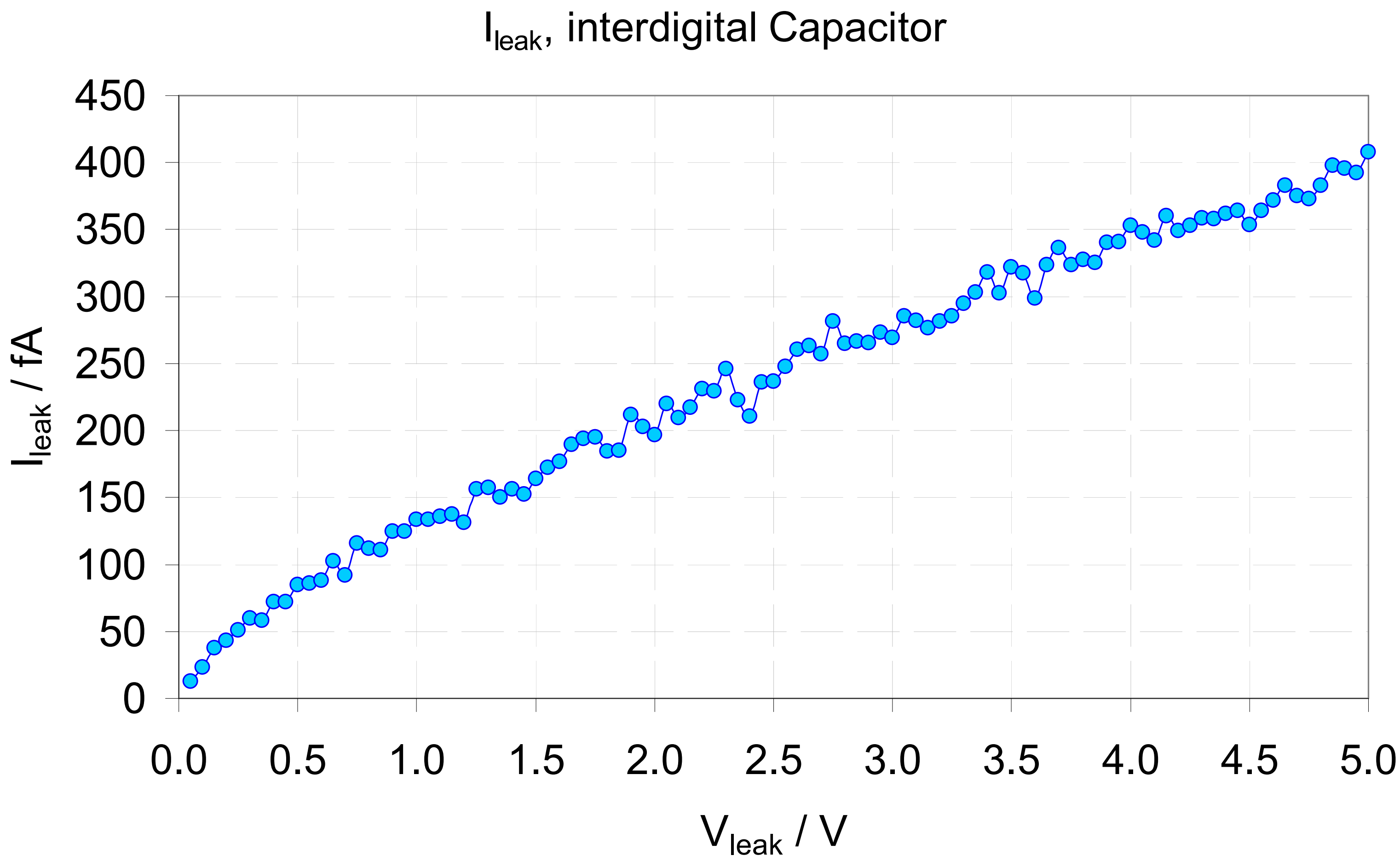
-Top electrode: polymer carbon
-Dielectric: PVP, 1.5 µm thick
– ε_r : 6.4 (measured)

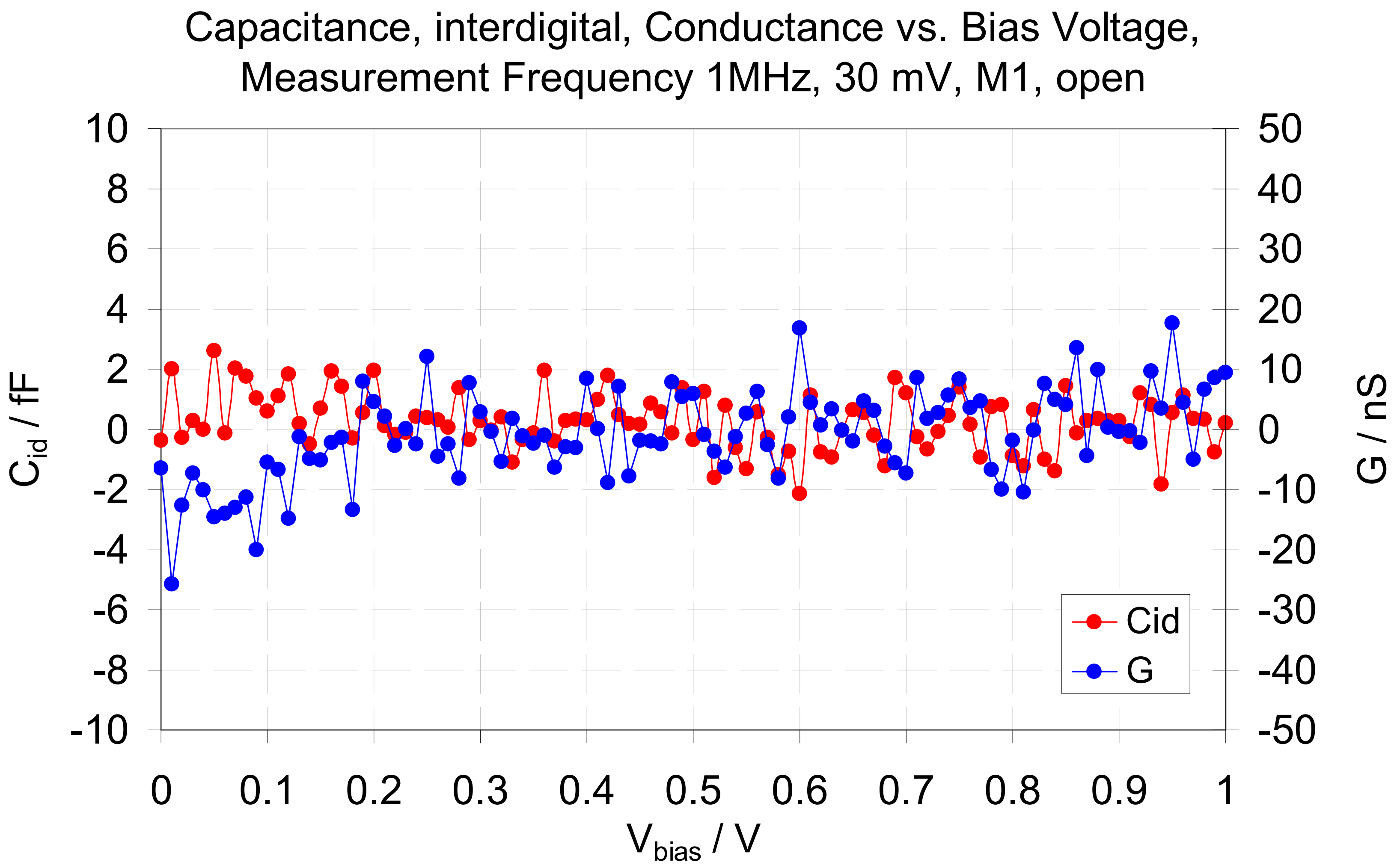
-C_{calc}: 37.8 pF/mm²

-Electrode areas S:
- 1 mm²
- 5 mm²
- 10 mm²
- 50 mm²

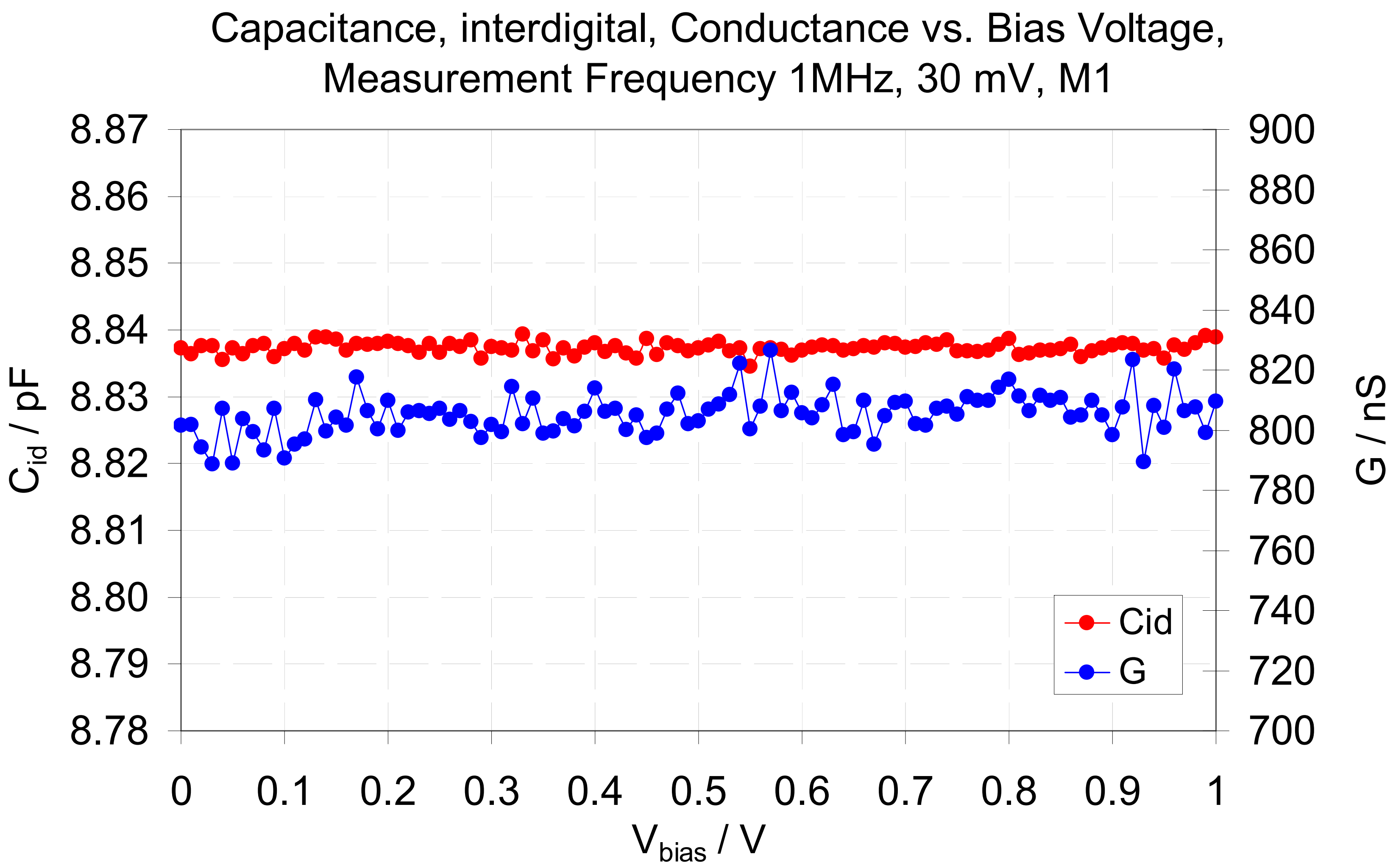
Interdigital Capacitor on PI- Foil, Leakage Current



Parasitic Capacitance of measurement Setup



Interdigital Capacitor on PI- Foil



Summary and Conclusions

- Integrated passive devices on flexible substrates were designed and realized in a Roll-to-Roll process
  - Design rules are similar to screen printed devices on rigid substrates
  - Thermal behavior of resistive passives is more critical
  - Power dissipation must be done by the resistive layer itself
  - Flexible substrates, like PET and PI have low thermal conductivities, < 1 W/m*K (Al_2O_3 10 W/m*K; AlN 170 W/m*K)
- Electrical measurements of integrated passive devices on flexible substrates show similar results with chip size passive devices
  - Limitations because of polymer versus inorganic materials
- Adjustment of integrated passive devices with laser trimming possible

Final Conclusion