Wrocław University of Technology

The Influence of Thermal Process on Electrical Conductivity Microstructures Made by Ink Containing Nano Sized Silver Particles

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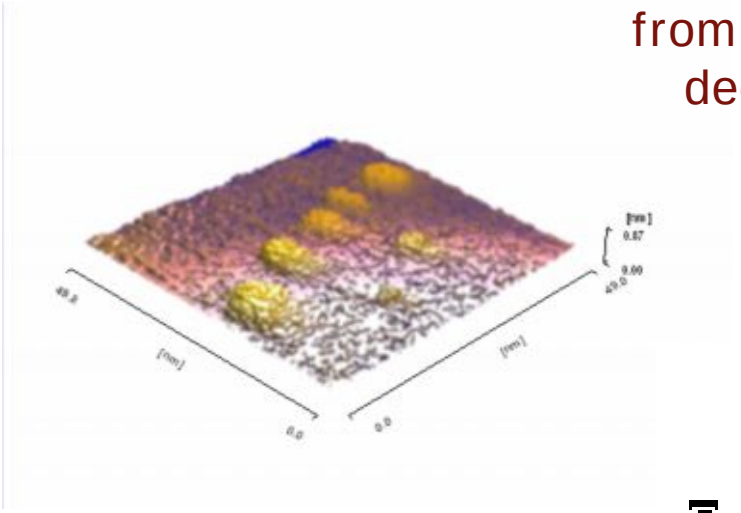
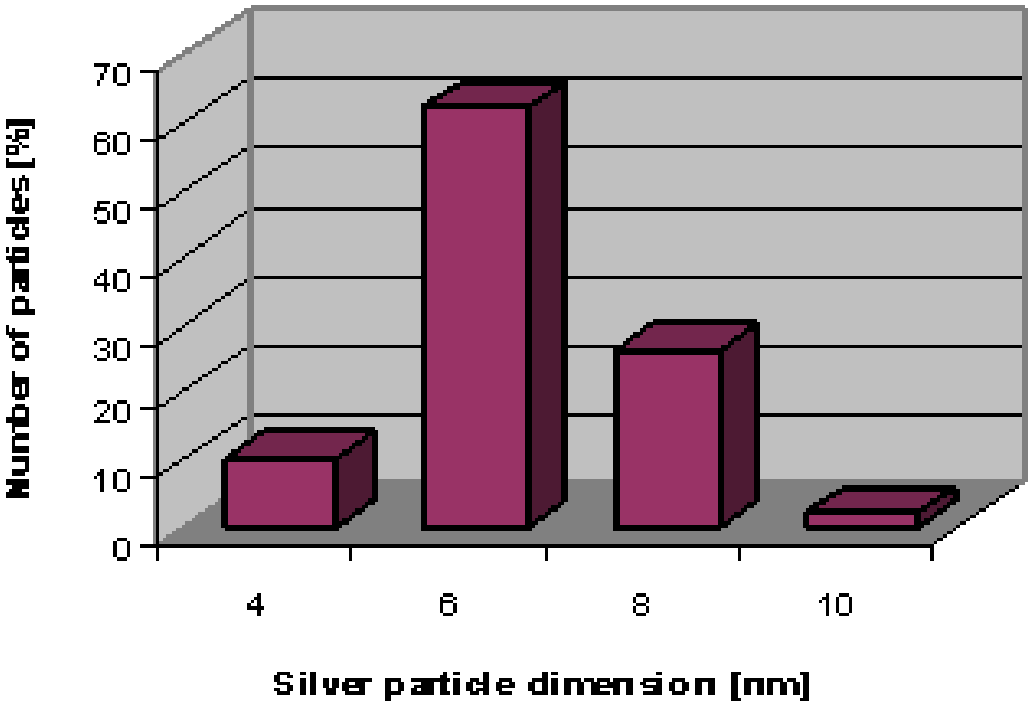
SILVER

from Ag salts of fatty acids during their thermal decomposition in an oxygen-free atmosphere



STM picture



Size distribution

THE INK

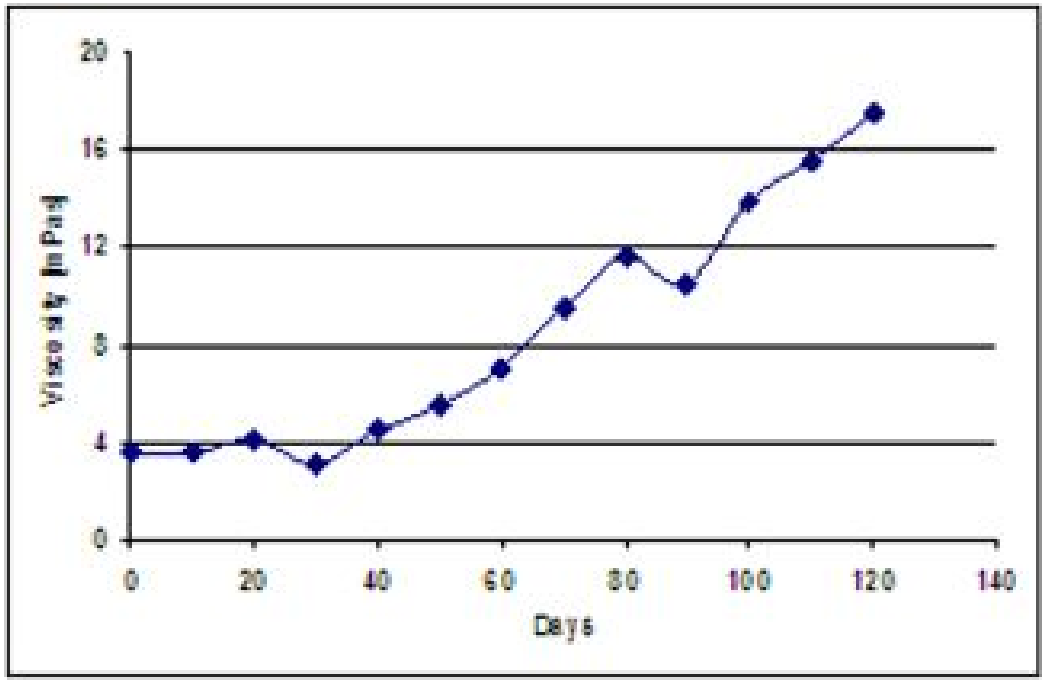
Solvent:
tetradecan

Number of components	One
Consistency	Very low viscous fluid
Color	Dark brown to black with metallic shane
Percentage of silver filler	~ 50 %
Viscosity*)	3.6 ÷ 18 mPas
Thixotrophy index	~ 1.0
Surface tension value	28.5÷32.5mN/m
Specific gravity	1.3 ÷ 1.6 g/cm³
Electrical resistivity**)	(1 ÷ 3) 10^{-5} Ωcm

*)Brookfield LVDVII + CP; 100 rpm; 20 °C
**) after 230 °C; 60 min sintering

THE INK

Viscosity



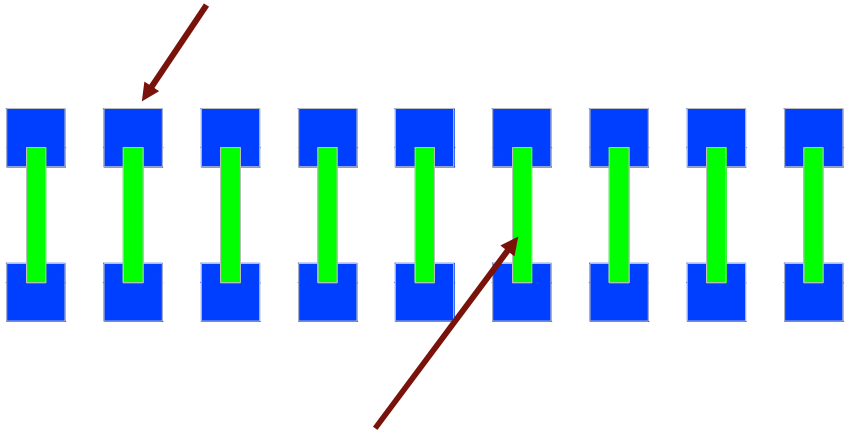
Sedimentation: 0.4 %/20 days

PRINTED STRUCTURES

Dimatix DMP-2831 printer

- 12 Nozzles: 22.5 µm diameter
- Maximum jetting frequency: 5 kHz
- Drops volume: about 10 pl

First step: 9 pairs of contacts (3 x 3 mm) were printed and sintered 1 hour in temperature of 250 °C

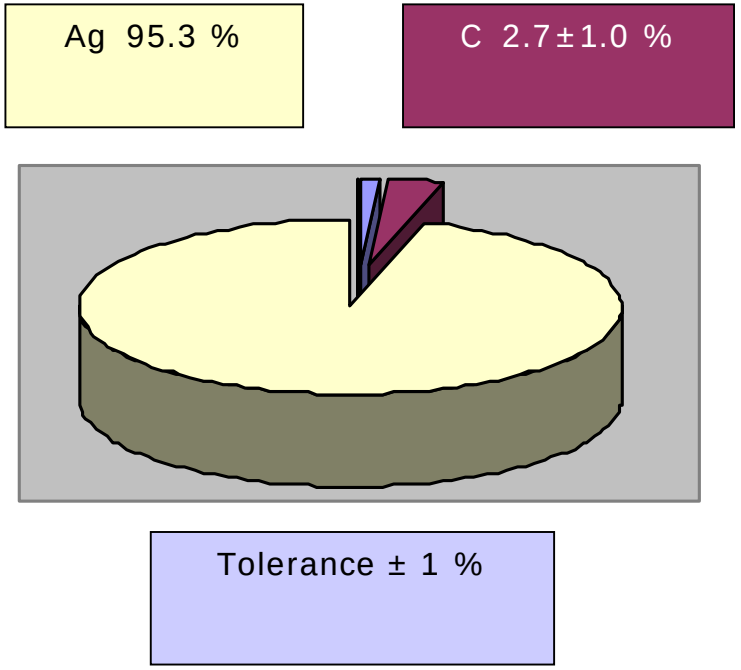


Second step: paths with 1 mm with were printed joining contacts. The distance between contacts: 3.4 mm or 8.8 mm. Structures were drying by a few seconds in temperature of 110 °C

ELECTRICAL RESISTIVITY

JUST AFTER PRINTING: Resistivity → ∞

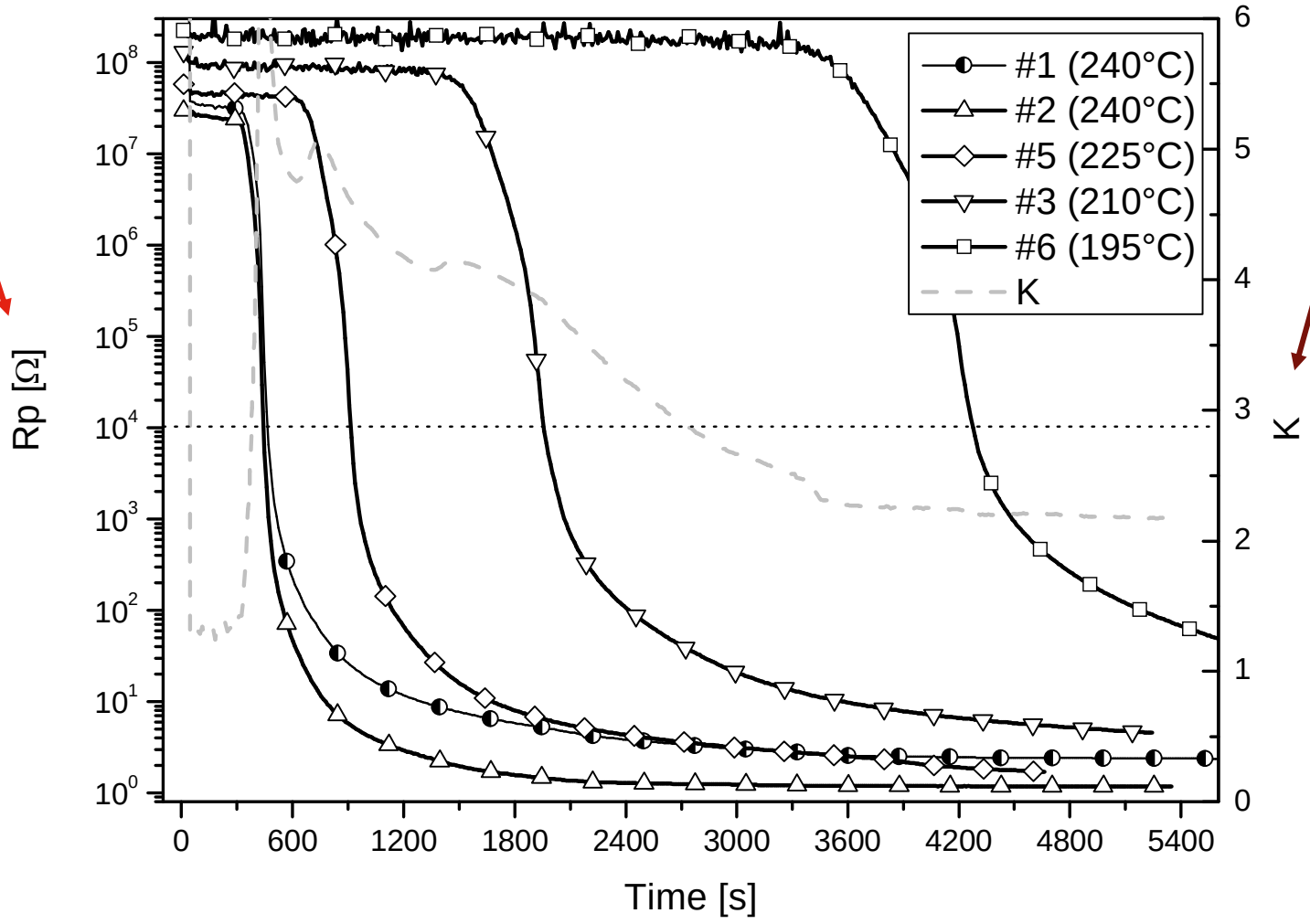
Each nAg particle is protected by special chemical „schell”. This „schell” layer was build during nAg production process



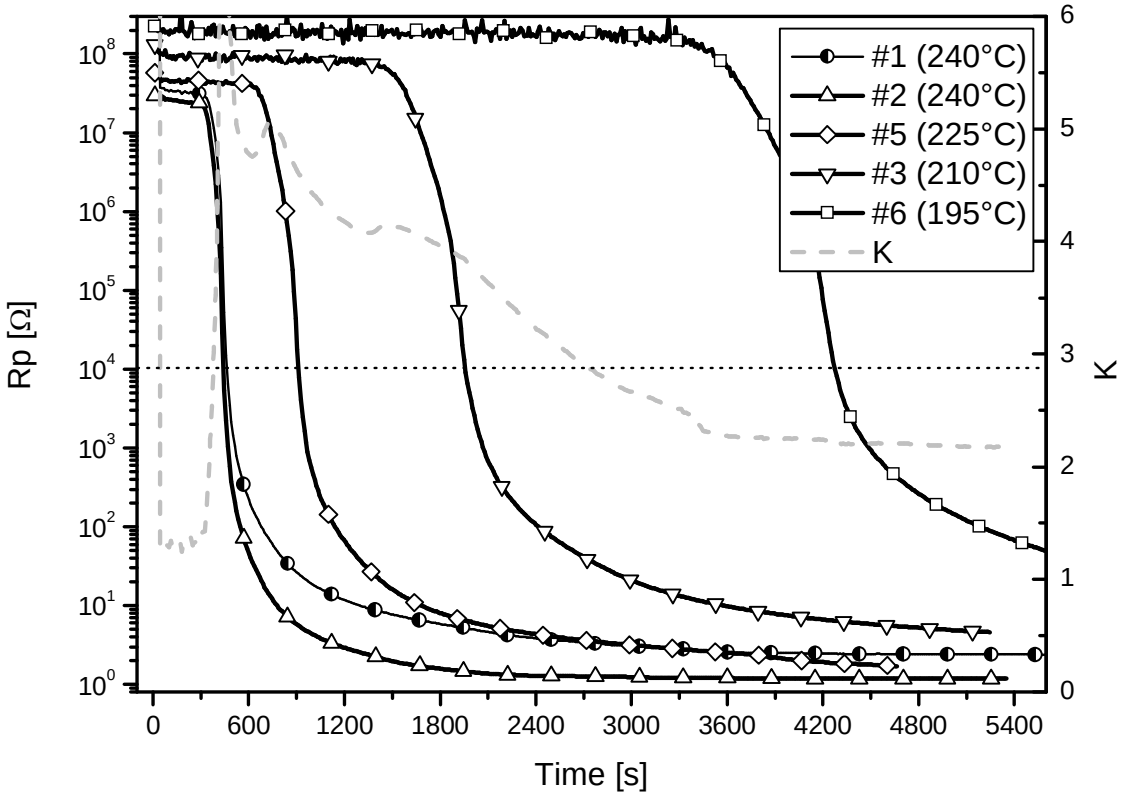
THERMAL PROCESS

Resistance

Factor *K*: takes into account the influence of measuring system



THERMAL PROCESS



THREE STAGES:

1° - in sintering temperature the high resistance remains stable,

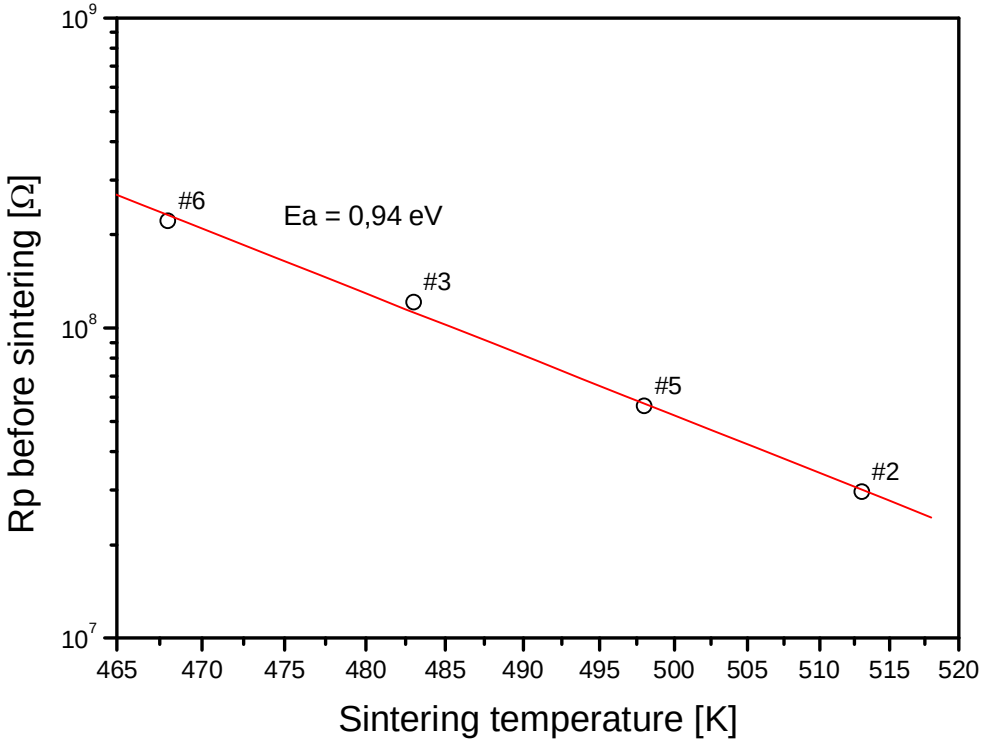
2° - resistance decreases in relatively short period of time,

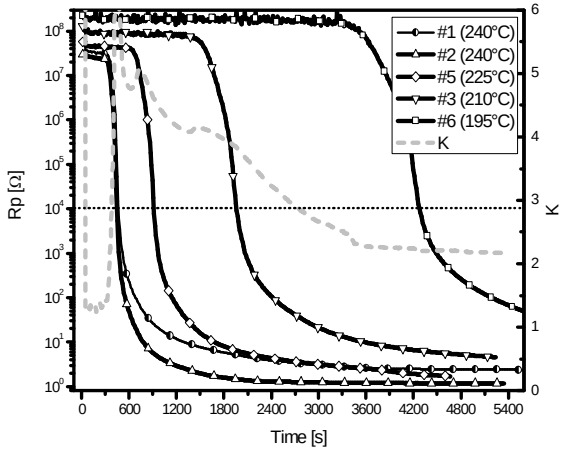
3° - low resistance changes during the thermal process.

CONCLUSIONS:

- final resistance is almost the same for the range of 195 °C – 240 °C temperature changes,
- the time of the first stage is much longer with lower temperature.

THERMAL PROCESS





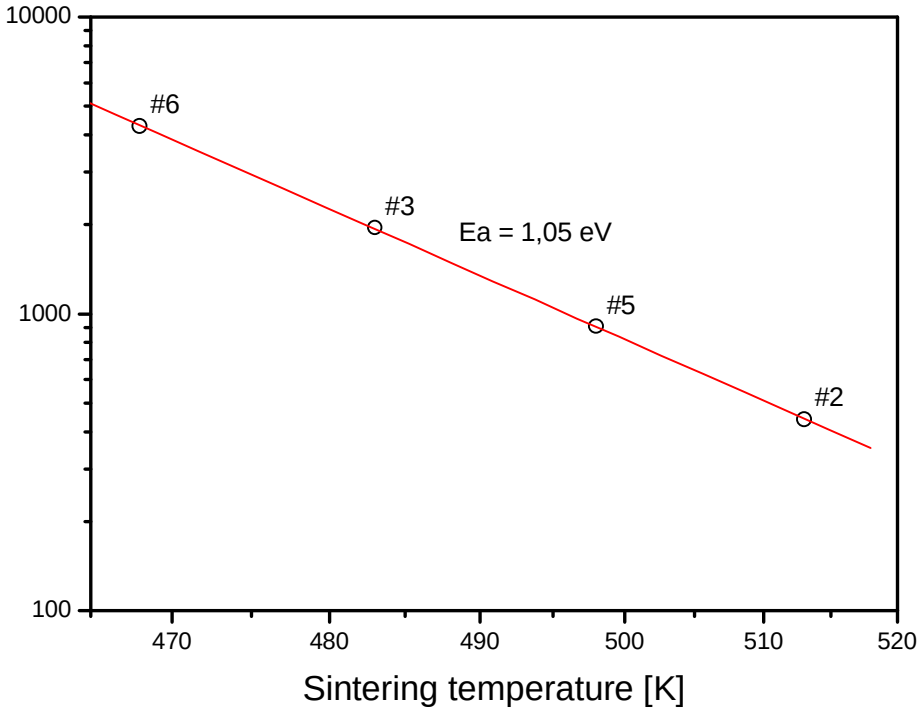
IN THE BEGGING OF THE SINTERING PROCES:

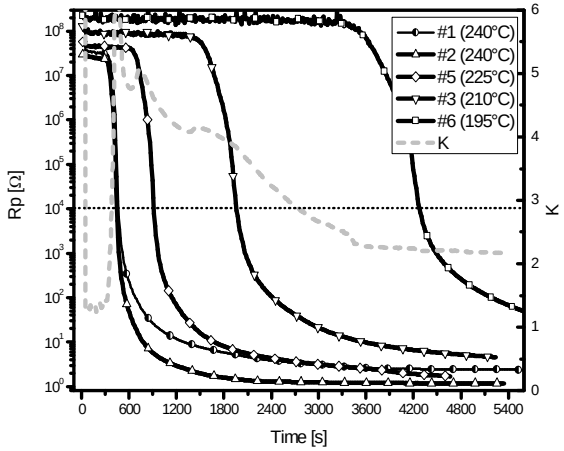
- the resistance for the same type of samples depends on temperature

CONCLUSIONS:

- So high activation energies (0.94 eV) may suggests the ionic type of conductance.

THERMAL PROCESS





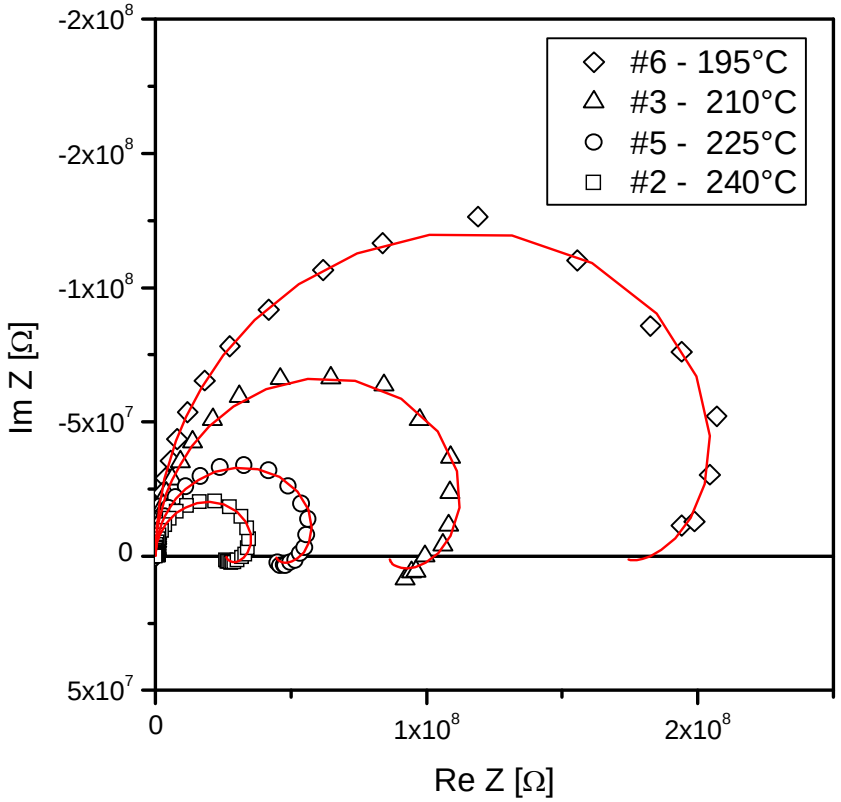
Dependence of sintering time on sintering temperature

$$t = 2{,}32 \cdot 10^{-8} \exp\left(\frac{1{,}05eV}{kT}\right)[s]$$

CONCLUSIONS:

- The phenomenon of sintering process is consistent with Arhenius law with activation energy of 1.05 eV. Probably there is a very quick reaction with that activation energy.

THERMAL PROCESS



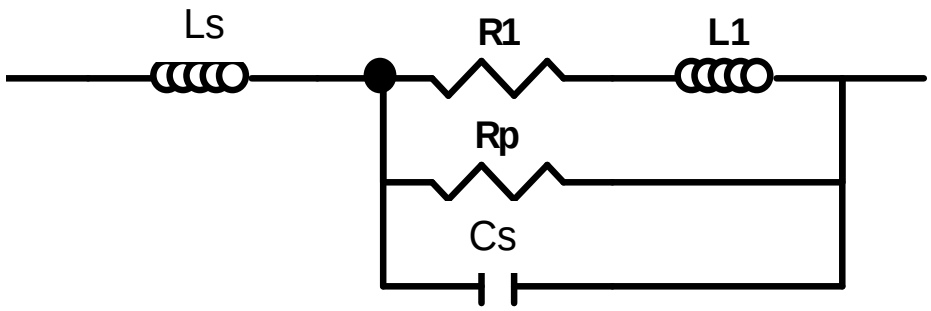
NYQUIST PLOTS of measured samples (real and imaginary parts of impedance are presented):

for short sintering times, the plots pass on positive values imaginary part of impedance

CONCLUSIONS:

➢It is typical for impedance measurement of an object in with Faradaic process takes place

THERMAL PROCESS



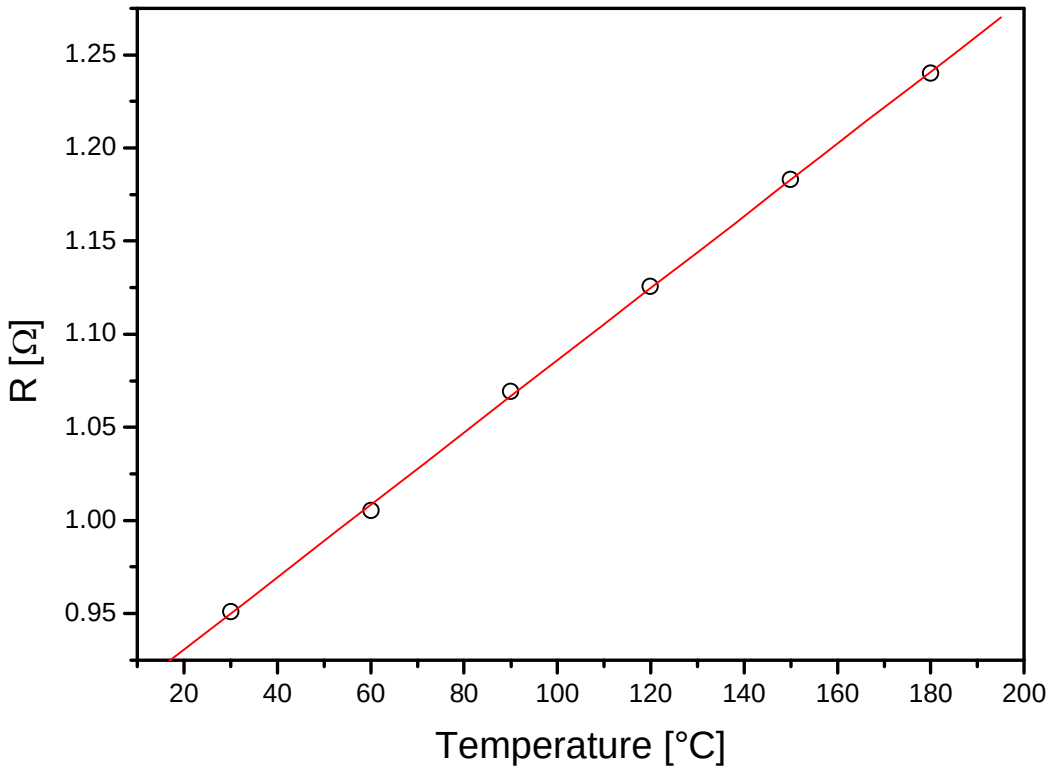
THE EQUIVALENT CIRCUIT (describing experimental plots)

The branch R1-L1 is responsible for the phenomena, while the Rp represents the resistance of the printed structure and both Ls and Cs - the self-inductance and self-capacitance of the measurement system.

CONCLUSIONS:

- The L1 cannot be treated as real inductance. It is caused by the reactions which output is the same as “normal” inductance, but in fact it is not connected with energy storage. Along with staring the second stage of sintering process (sudden drop of resistance value), the R1 – L1 branch disappears

AFTER THERMAL PROCESS



RESISTANCE VALUE DEPENDS ON OPERATION TEMPERATURE

CONCLUSIONS:

- This is typical metallic type of conductance with temperature coefficient of resistance equal 2080 ppm/K. It is lower value than for bulk silver (3800 ppm/K).

CONCLUSSIONS

TO OBTAIN GOOD ELECTRICAL CONDUCTIVITY, THE PRINTED STRUCTURES NEEDS ADDITIONAL ENERGY, MAINLY DURING A HEATING PROCESS. IT IS SHOWN, THAT THERMAL PROCESS INFLUENCES STRONGLY THE RESISTANCE ON THE PRINTED STRUCTURES AND DIFFERENT PHENOMENA TAKE PLACE DURING THIS SINTERING PROCESS:

- ON THE BEGINNING OF THE HEATING, THE REACTION WITH ACTIVATION ENERGY OF 1.05 EV IS OBSERVED; THE HIGHER TEMPERATURE CAUSES LOWER RESISTANCE,
- DURING THE HEATING PROCESS, THE STABLE, VERY HIGH RESISTANCE VALUE STAYS THE LONGER, THE TEMPERATURE IS LOWER, - THE PROCESS OF RESISTANCE DECREASING IS RELATIVELY SHORT, BUT RECEIVING THE FINAL CONDUCTANCE NEED ADDITIONAL TIME IN WHICH THE RESISTANCE DECREASES SLOWLY,

CONCLUSSIONS

TO OBTAIN GOOD ELECTRICAL CONDUCTIVITY, THE PRINTED STRUCTURES NEEDS ADDITIONAL ENERGY, MAINLY DURING A HEATING PROCESS. IT IS SHOWN, THAT THERMAL PROCESS INFLUENCES STRONGLY THE RESISTANCE ON THE PRINTED STRUCTURES AND DIFFERENT PHENOMENA TAKE PLACE DURING THIS SINTERING PROCESS:

- THE PHENOMENON OF SINTERING PROCESS IS CONSISTENT WITH ARHENIUS LOW WITH ACTIVATION ENERGY OF 1.07 EV,
- THE IMPEDANCE ANALYSIS SUGGESTS THE OXIDATION CHEMICAL REACTION DURING THE SINTERING PROCESS,

AFTER SINTERING PROCESS, THE CONDUCTIVE STRUCTURES HAVE IS TYPICAL METALLIC TYPE OF CONDUCTANCE WITH TEMPERATURE COEFFICIENT OF RESISTANCE EQUAL 2080 ppm/K.