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Dependency of silver nanoparticles protective layers on sintering temperature of printed conductive structures

Anita Smolarek[1)], Andrzej Mościcki[1)], Andrzej Kinart[1)], Jan Felba[2)], Tomasz Falat[2)]
[1)]Amepox Microelectronics, Ltd., Lodz, Poland
[2)]Wroclaw University of Technology, Faculty of Microsystem Electronics and Photonics, Wroclaw, Poland
axlab@amepox.com.pl

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General specification for Ink-Jet Printer

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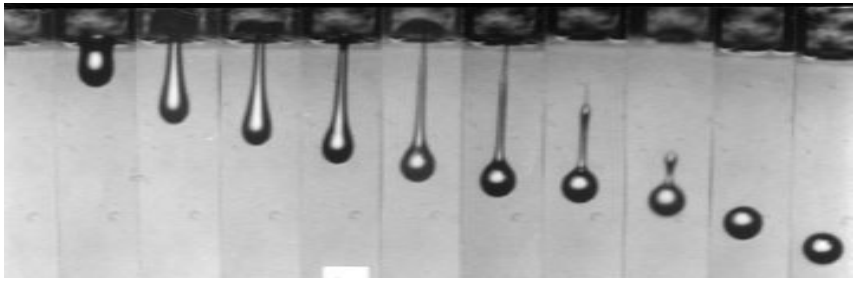
Nozzle diameter	10-100 μm
Droplet diamter	10 – 500 picoliters
Drop speed	1,5-2,5 m/s
Drop rate*	2000/s
Max. Throughput	0.5 μl/s
Viscosity range	0,5 – 20 mPas (unheated) 20-10000 mPas (heated)

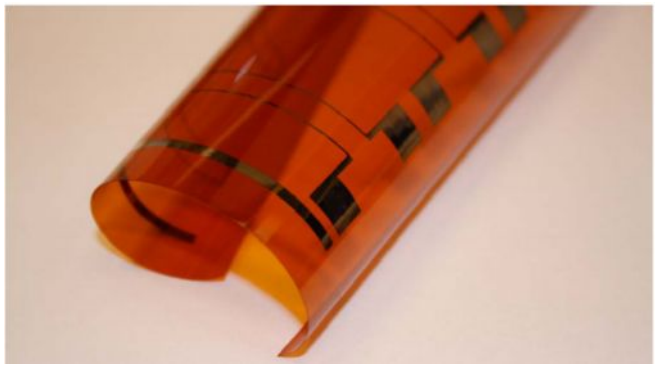
** depending on the liquid and capilar diameter*

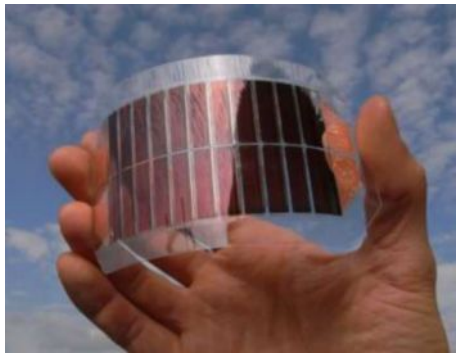


Actual and future research

The commercially available ink → The ink challenge

- Viscosity – 4 – 15,5 mPas
- Conductive filler - Ag
- Resistivity – 3 - 4 μΩcm
- Sizes of silver – 3 – 8 nm → 40 – 60 nm
- Content of silver – 40 – 50 % → 20 %
- Sintering temperature – 250 °C → 100 – 150 °C
- Printing possibilty - non-flexible substartes → flexible substrates





Slow Motion Shoot NanoInk by Ink Jet Dispenser

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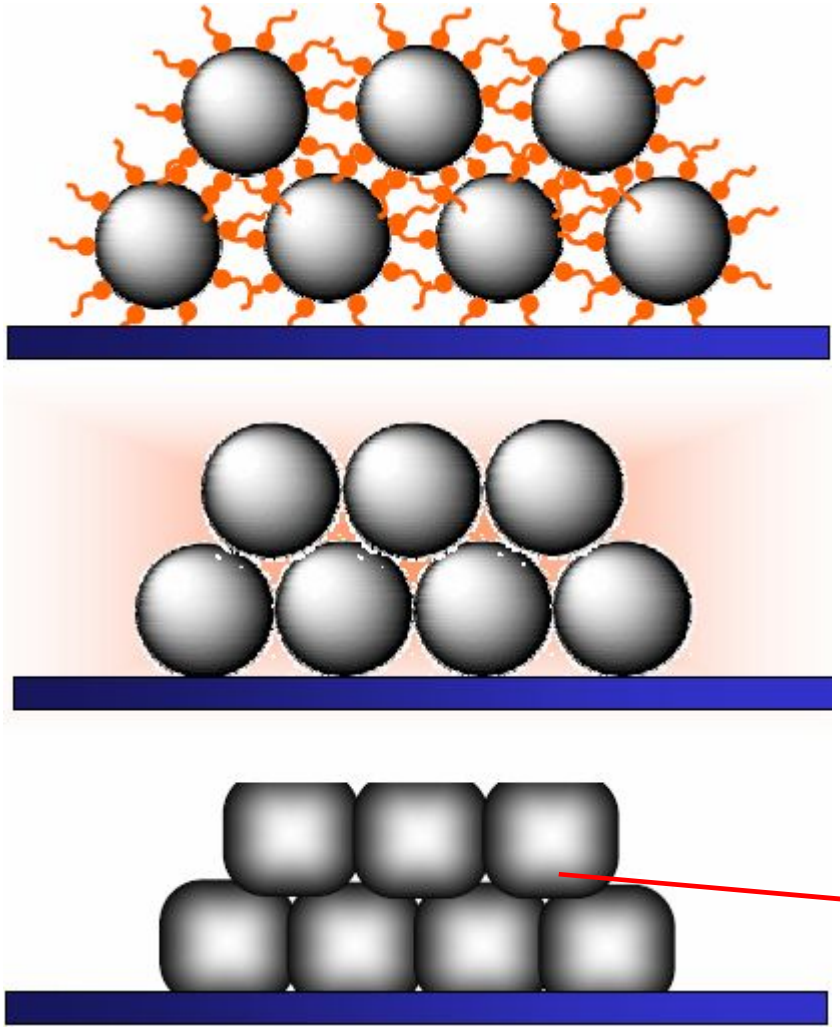
Phenomena during sintering process



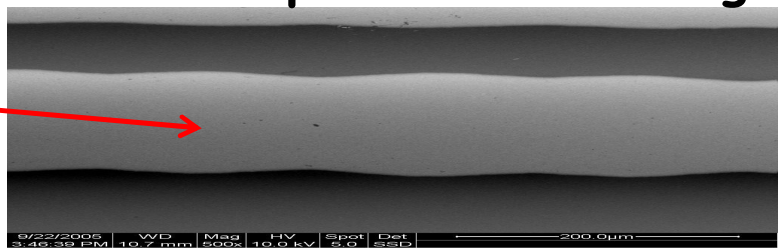
Evaporation of solvent

↓

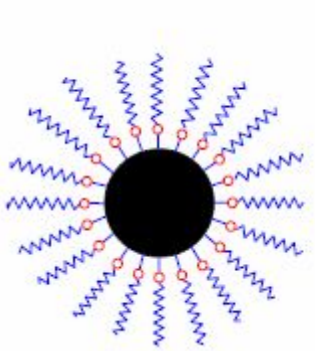
Removal of protection layers

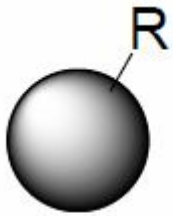
↓

Low – temperature sintering



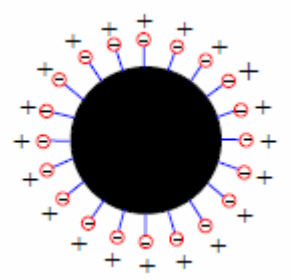
Polymer (steric):

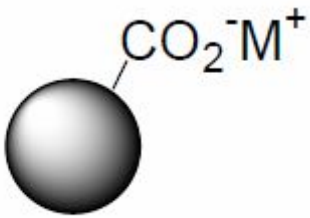




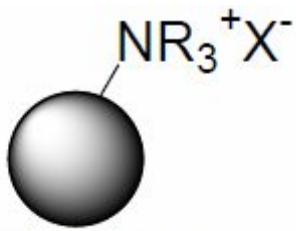
R: acrylic, polystyrene, PEO, PPO, etc

Charged (electrostatic):





Carboxylate



Tertiary amine

Type of studied nanosilver:

- nanosilver with **carboxylate** coating (*Ag1*),
- nanosilver with **amine** type coating (*Ag2*),
- nanosilver with **polymer** coating (*Ag3*).

Metalic NanoSilver as a Filler for Ink Preparation

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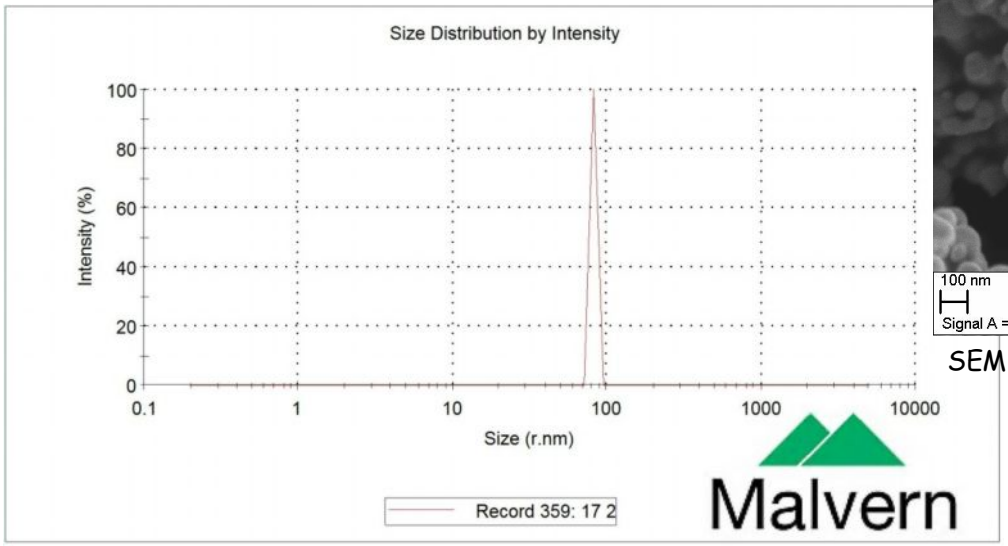
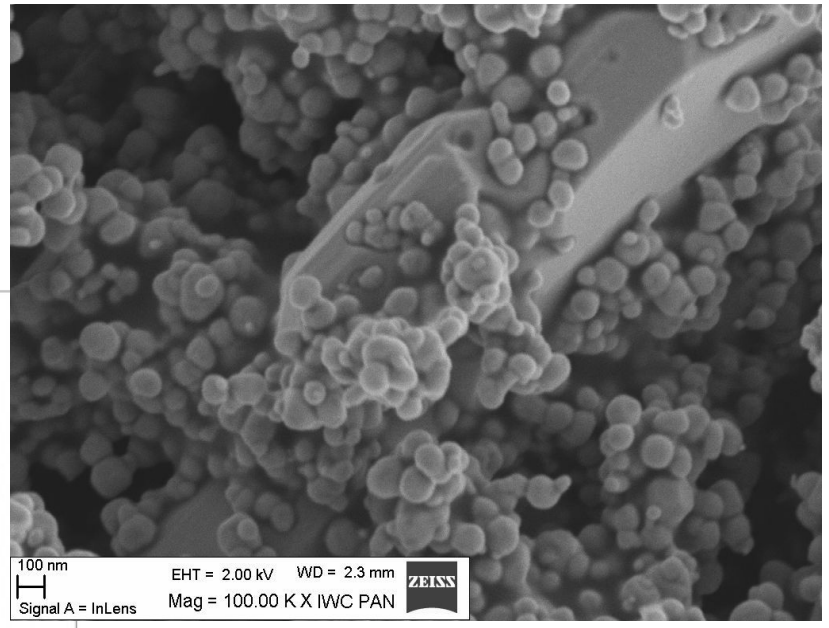
Nanosilver with carboxylate protective coating – Ag1



Measurement of particle size „Malvern" (Courtesy Polish Academy of Sciences)



SEM picture nAg particles (Courtesy Polish Academy of Sciences)

Size - 80–100 nm

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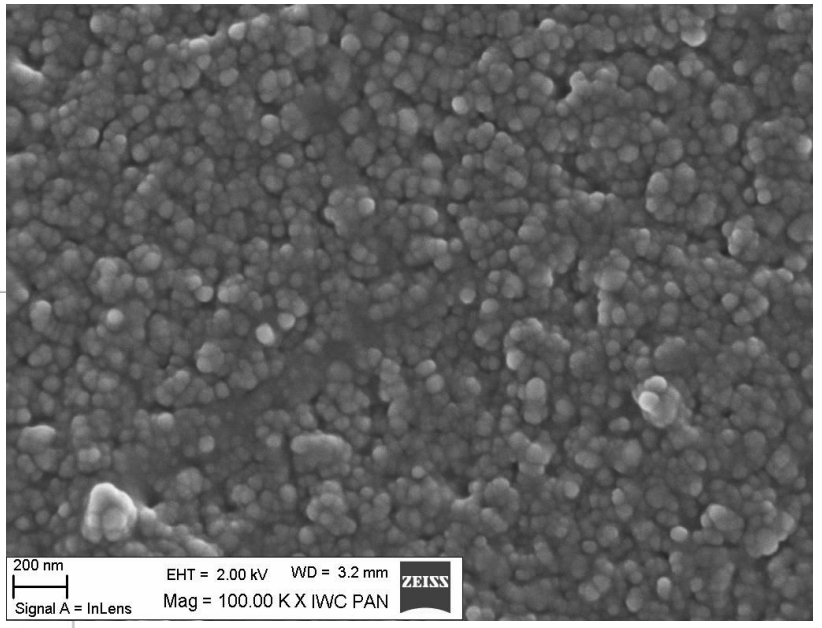
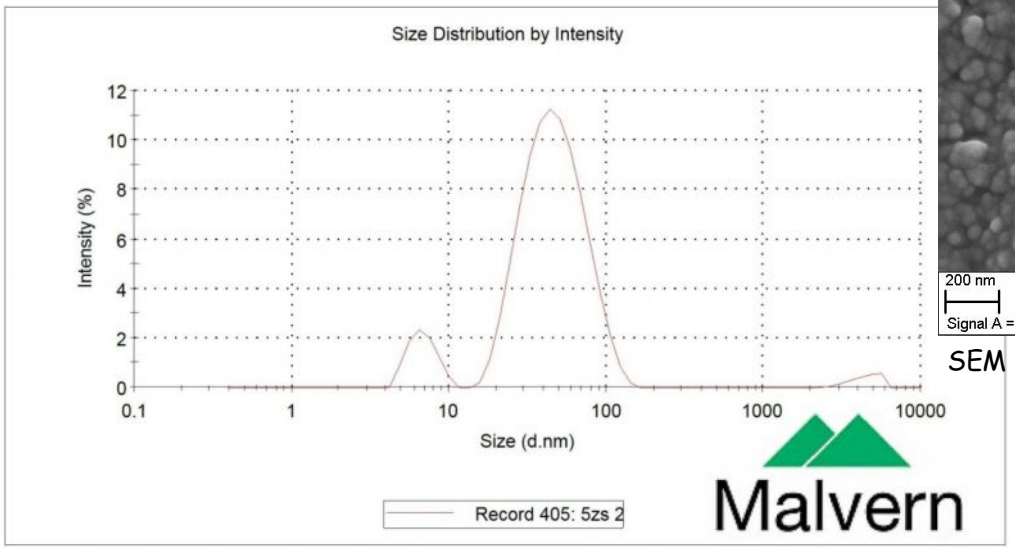
Nanosilver with amine protective coating – Ag2



SEM picture nAg particles (Courtesy Polish Academy of Sciences)



Measurement of particle size „Malvern" (Courtesy Polish Academy of Sciences)

Size – ab.50 nm

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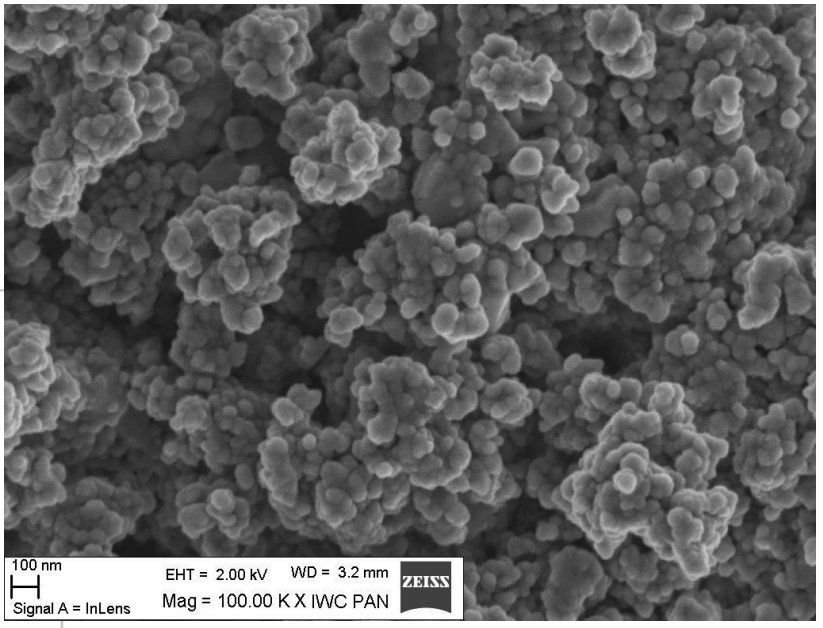
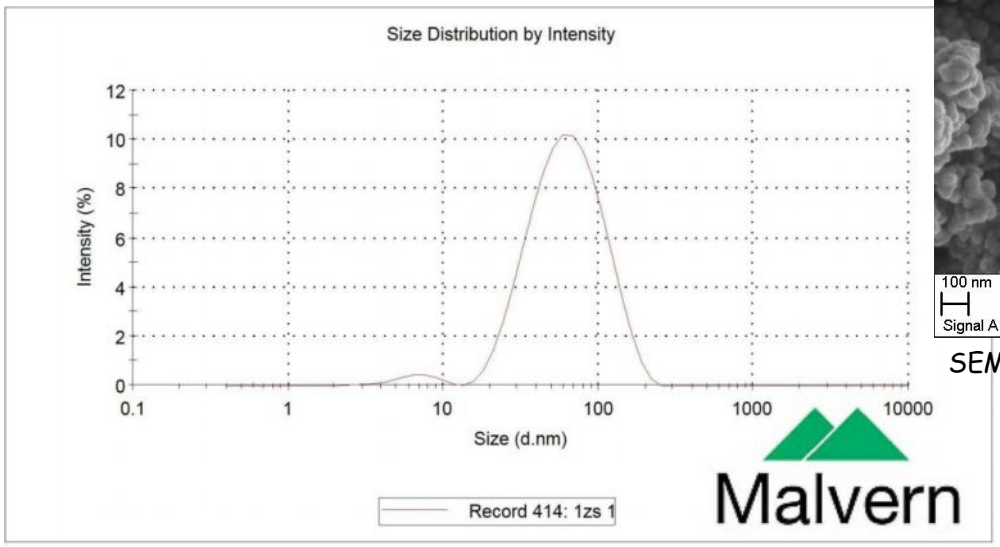
Nanosilver with polymer protective coating – Ag3



SEM picture nAg particles (Courtesy Polish Academy of Sciences)



Measurement of particle size „Malvern" (Courtesy Polish Academy of Sciences)

Size – 50-70 nm

Thermal studies:

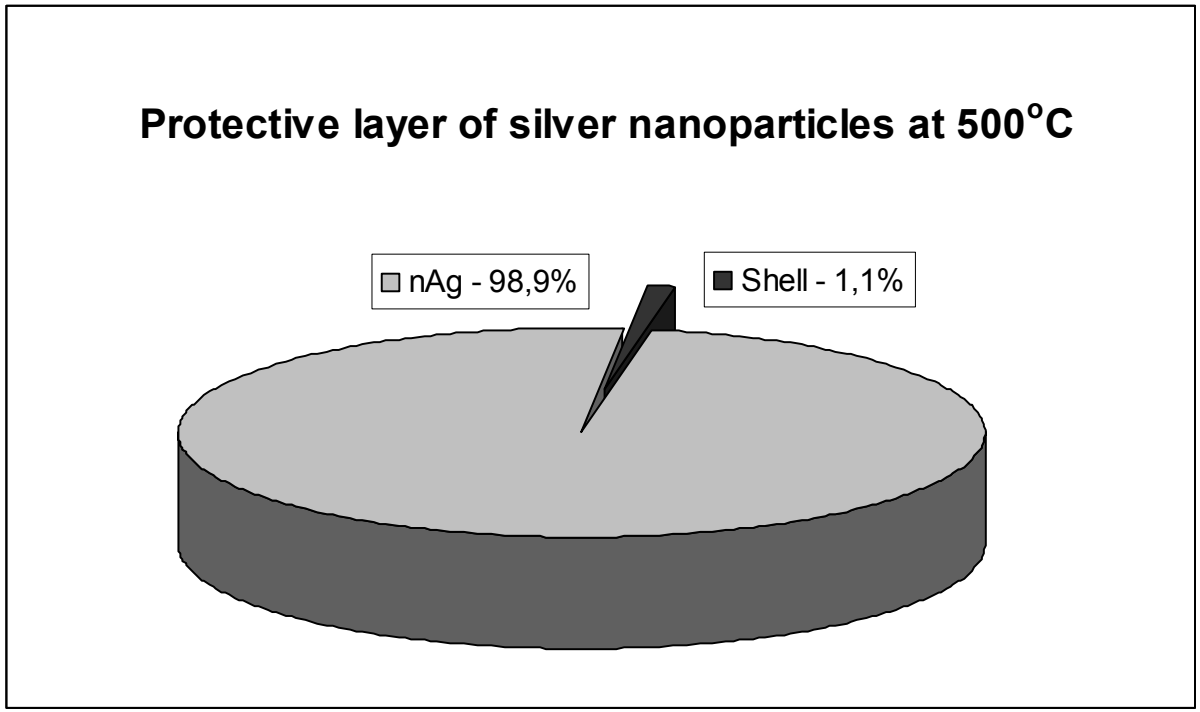
- the purity analysis for Ag1, Ag2 and Ag3 samples,

- the dynamics of removing the protective coating at 150 °C and 230 °C as a function of time for Ag1, Ag2 and Ag3 samples,

- the X-ray photoelectron spectroscopy (XPS) for nAg sample.

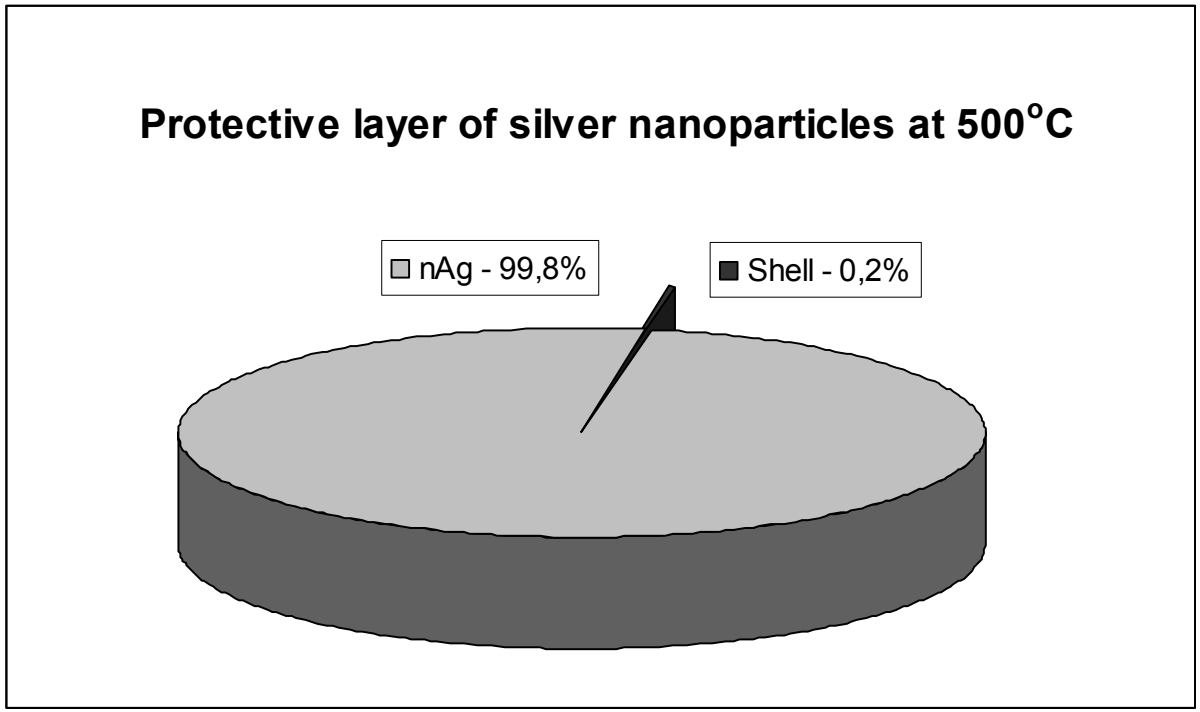
Purity analysis of nanosilver with carboxylate coating - Ag1:

- content of carboxylate coating – 1,1 %



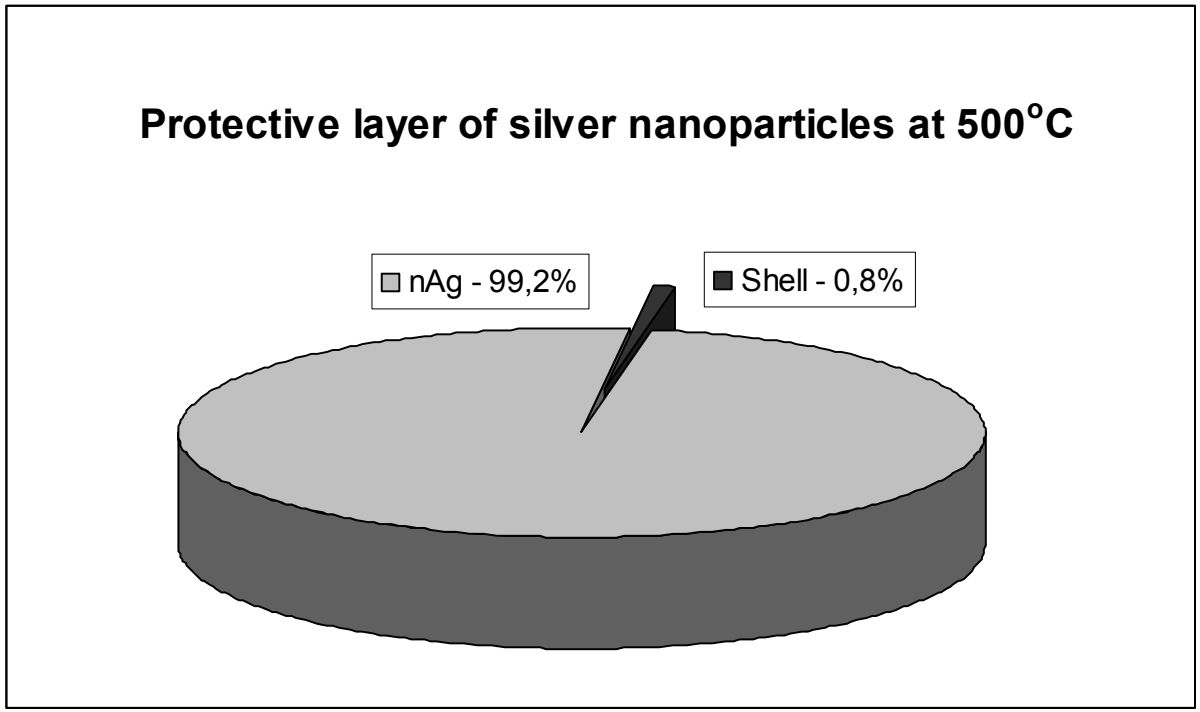
Purity analysis of nanosilver with amine coating – Ag2:

- content of amine coating – 0,2 %

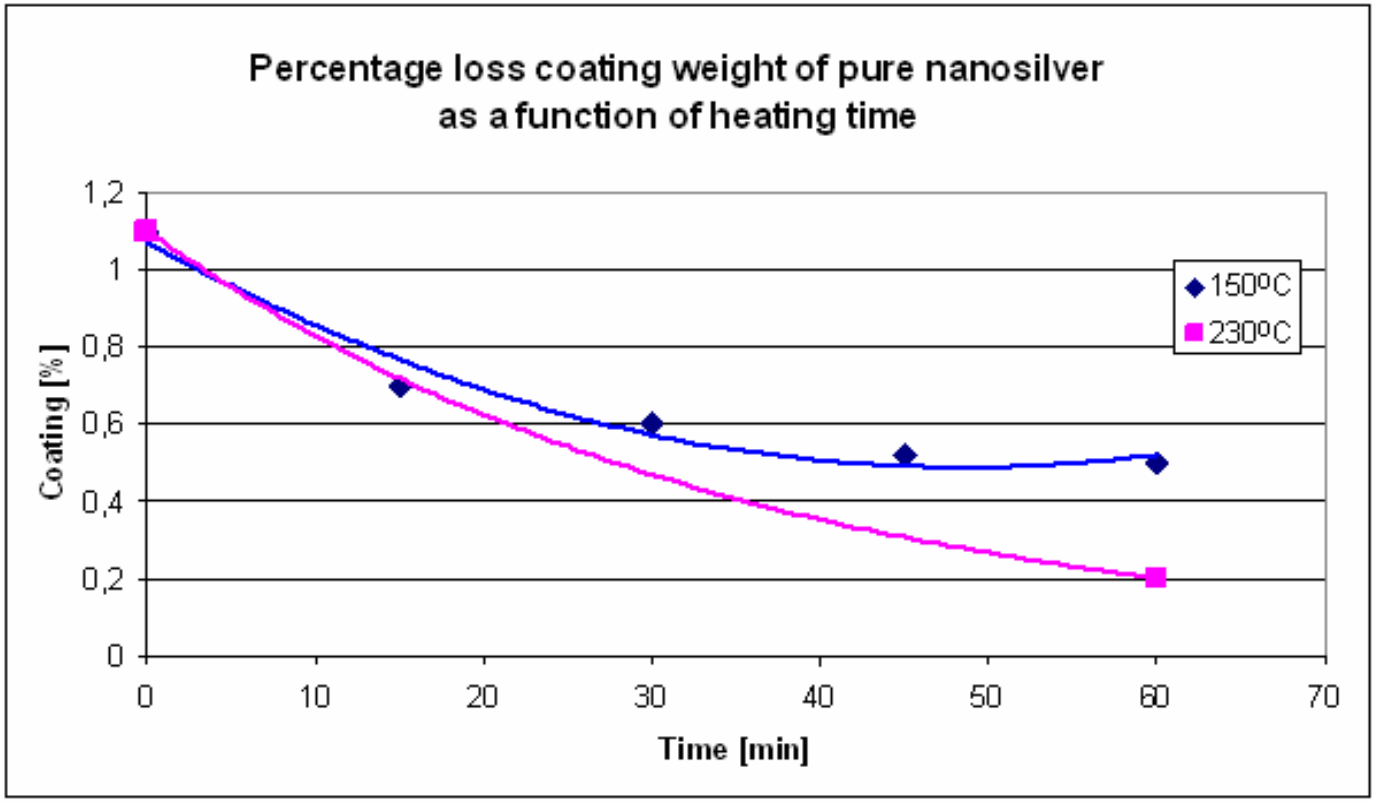


Purity analysis of nanosilver with polymer coating – Ag3:

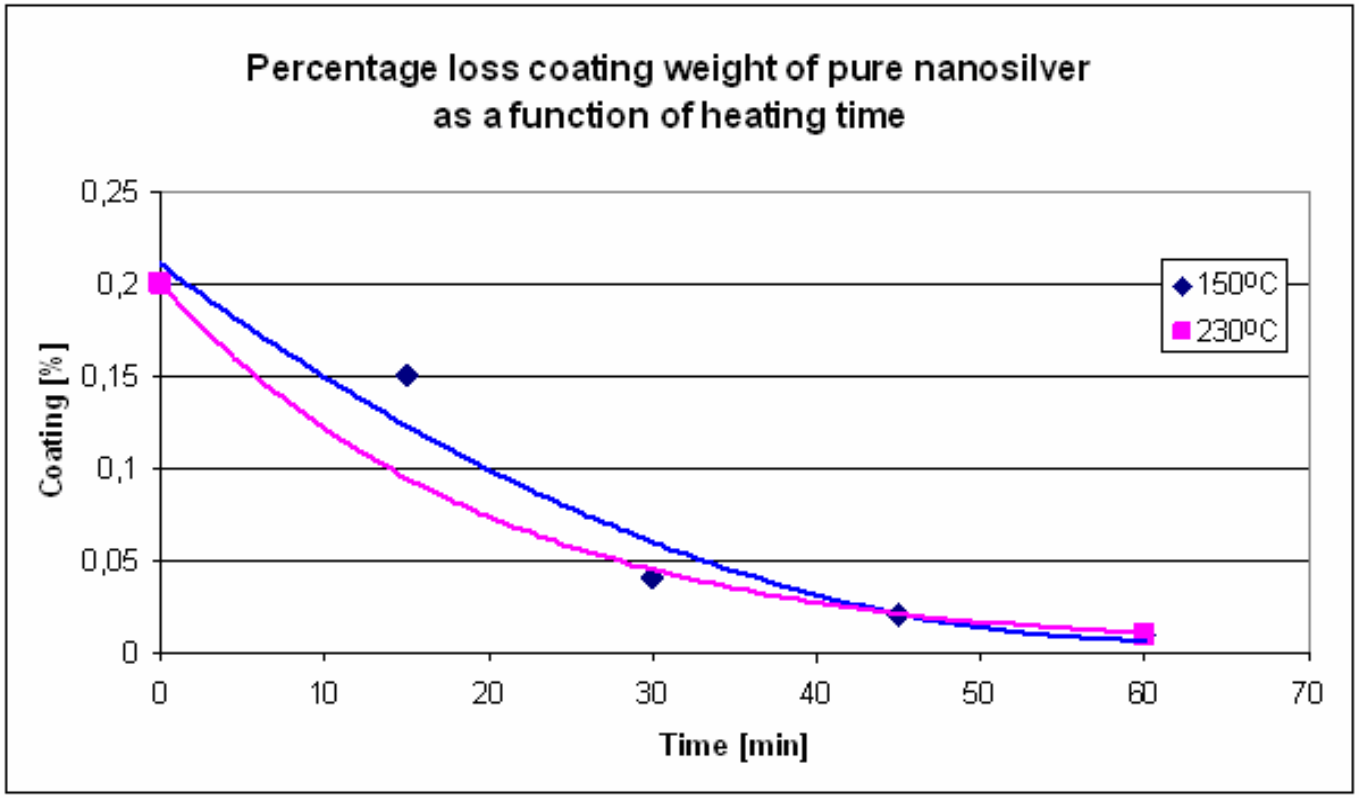
- content of polymer coating



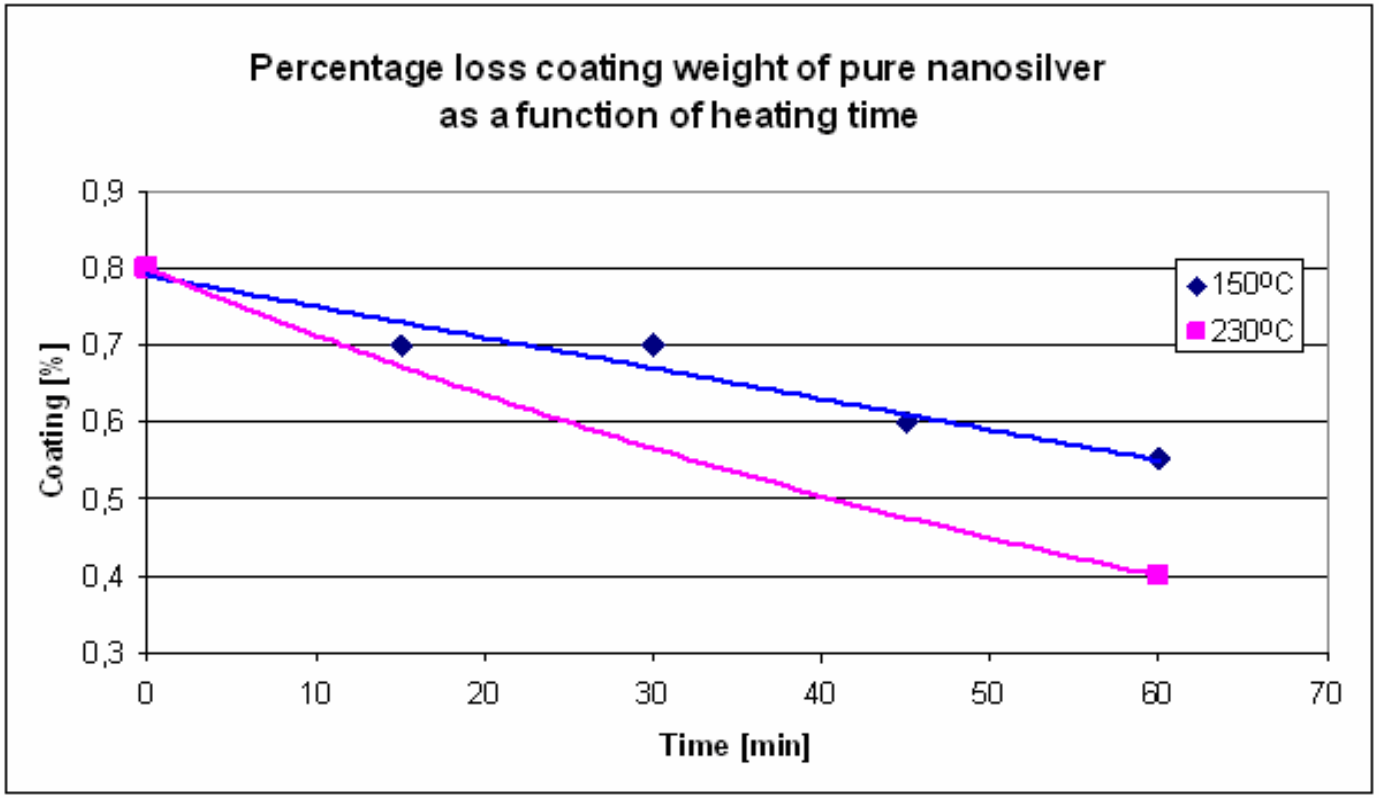
The dynamics of removing carboxylate coating at 150 °C and 230 °C as a function of time of Ag1



The dynamics of removing amine coating at 150 °C and 230 °C as a function of time of Ag2



The dynamics of removing polymer coating at 150 °C and 230 °C as a function of time of Ag3



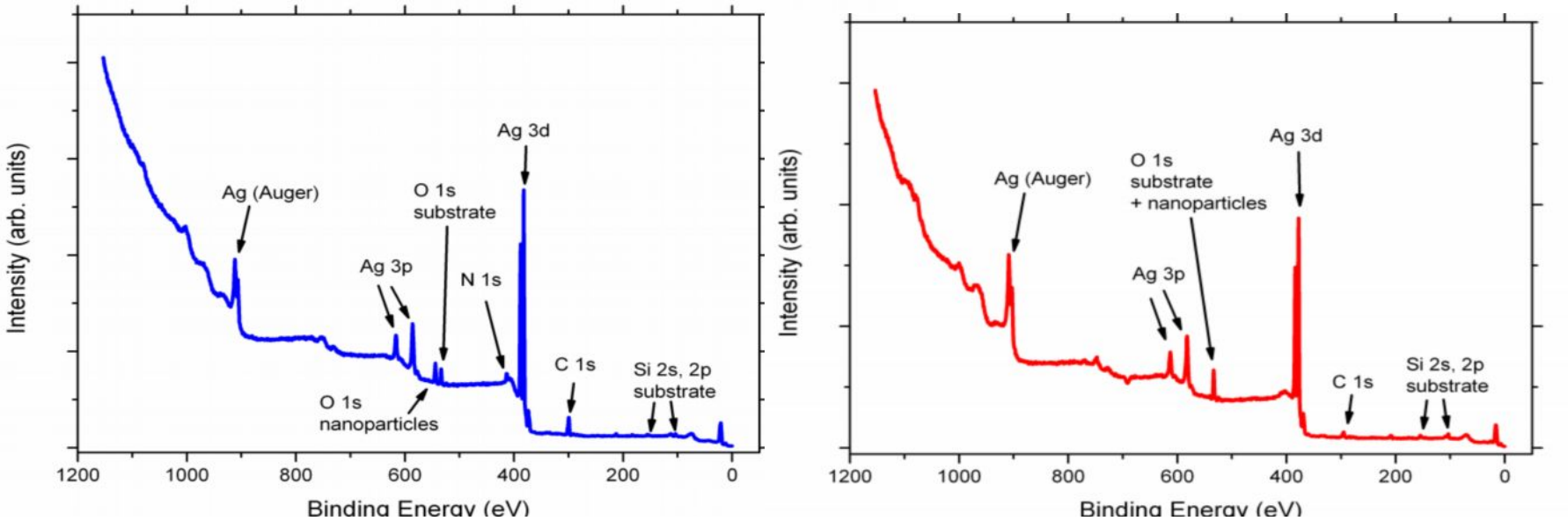
Example of XPS analysis for nAg before and after thermal process in ultra high vacuum up to 290 °C

Before

- *silver, carbon, oxygen & nitrogen;*

After

- *silver, small amount of carbon;*



XPS analysis (Courtesy University of Łódź)

Summary:

- We have shown three types of protective layers as a representative from very wide group of materials.

- Different size of obtained nAg is connected with reaction conditions for diffrent group of used materials.

- We have made the studies of % content of protective layers on surface each kind of nanosilver.

- The dynamics of removing protective coating at heating tempertaure as a function of time were carried out.

- The maximum protection material was about 1.1 % for nanosilver with carboxylate coating and in the best case 0.2 % for nanosilver with amine type coating.

- The remainted amount of protective layers is necessary for improving adhesion of printed layer to substrates.

Thank you for your attention.

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