Filling the cavities of a printed thermoelectric generator

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Agenda

Part 1 - Andreas

- Printed thermoelectric generators
  - Thermoelectric effect / Seebeck effect
  - Challenge for printing technology
  - Fully printed thermoelectric generators (TEG)

Part 2 - Jochen

- Nickel inks

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Media University Stuttgart - HdM

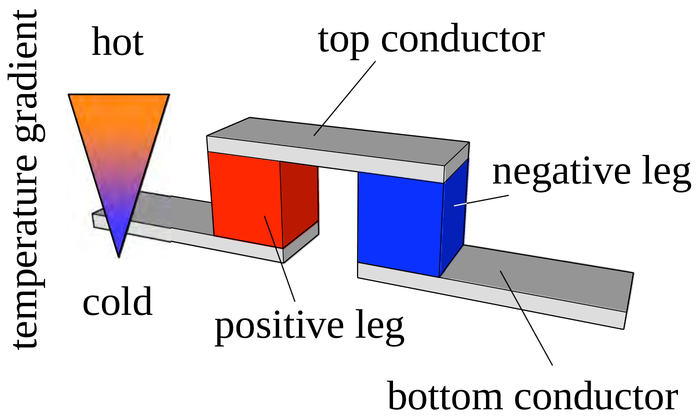
- Institute for Applied Research / IAF
- Subdivided in 25 groups, our group Innovative Applications of Printing Technologies (IAD)
- 5 projects: 3 governmentally funded, 2 funded by industrial partners directly
- Basically screen printing

Thermoelectric Effect

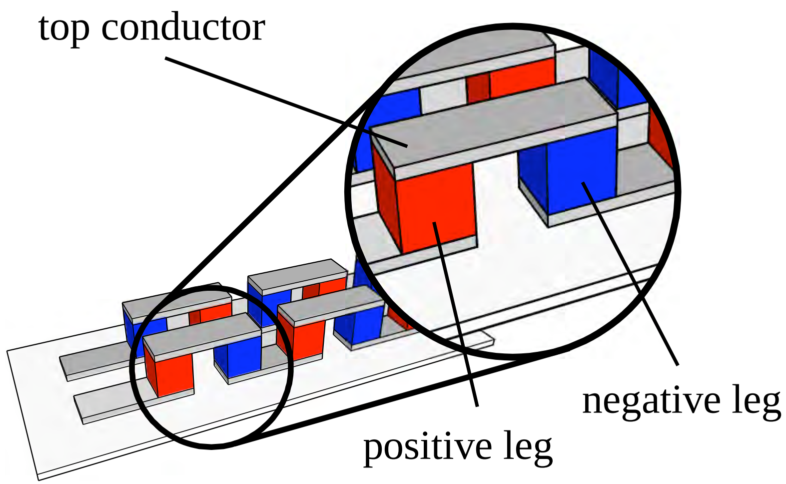
- Thomson-, Peltier- and Seebeck effect
- Thermoelectric Generator (TEG)
  > thermoelectric potential
- Seebeck effect:
  heat energy into electrical energy
- Material constant: Seebeck coefficient

Seebeck Effect

single thermocouple



series connection



Required:

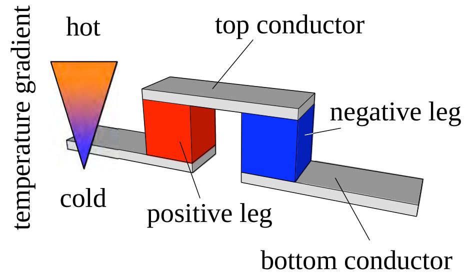
- very different Seebeck coefficients
- persistent temperature gradient

Seebeck coefficients

positive leg	
Tellurium	+49
Silicon	+44
Antimony	+4.0
Nickel chrome	+1.45
Iron	+1.08

negative leg	
Lead	-0.31
Tin	-0.33
Aluminium	-0.36
Nickel	-2.25
Bismuth	-7.25

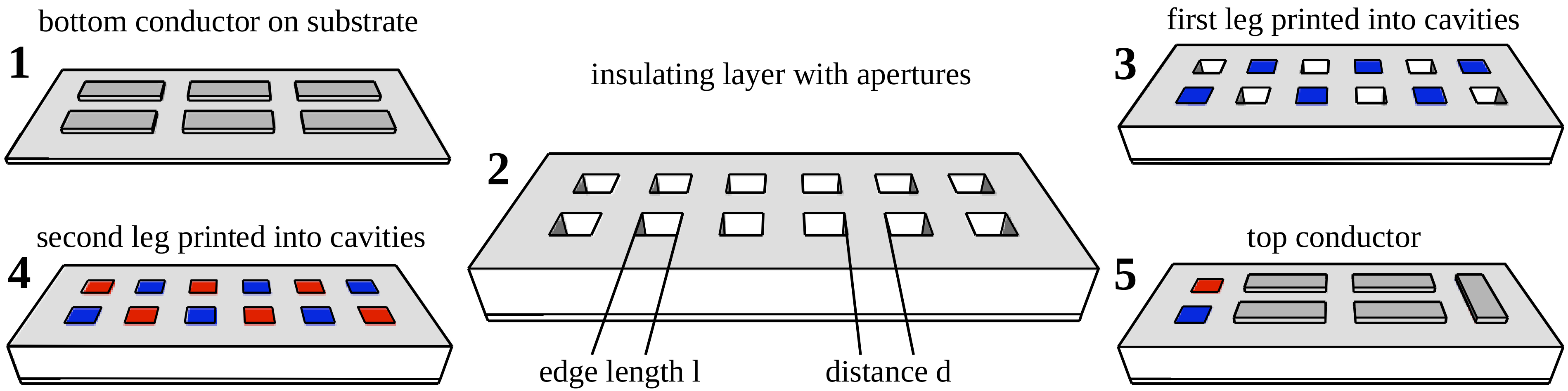
single thermocouple



2^{nd} leg: Copper
hot side: 100°C
cold side: 0°C

Stöcker, Taschenbuch der Physik, Thermoelectric series of some materials

Vertical layout with insulating layer

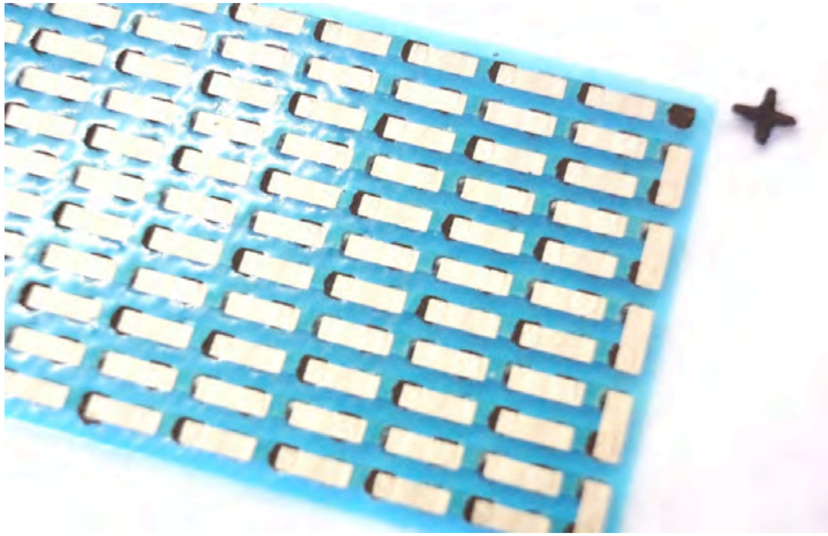


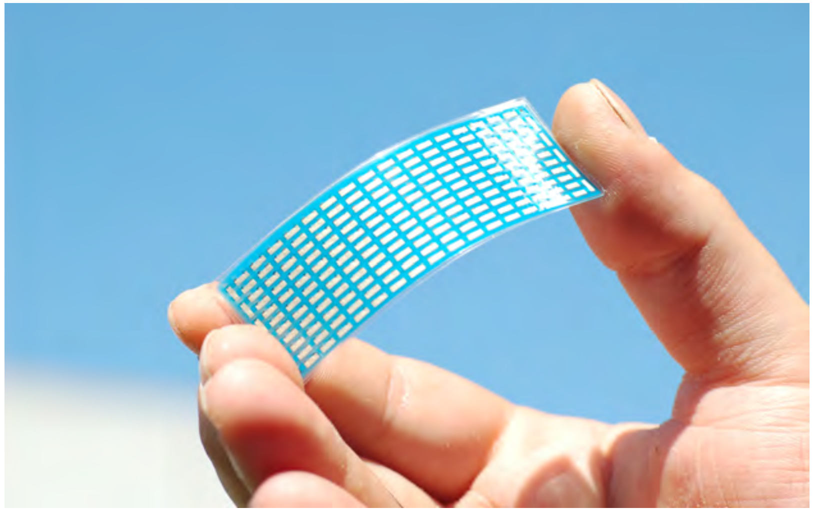
Problems:

-Inks with high Seebeck coefficients

-Printing into deep cavities (50 to 200 µm)

Printed Thermoelectric Generator





Already accomplished:

- Thin, flexible fully printed TEG
- Thermoelectric legs: PEDOT:PSS&Ni

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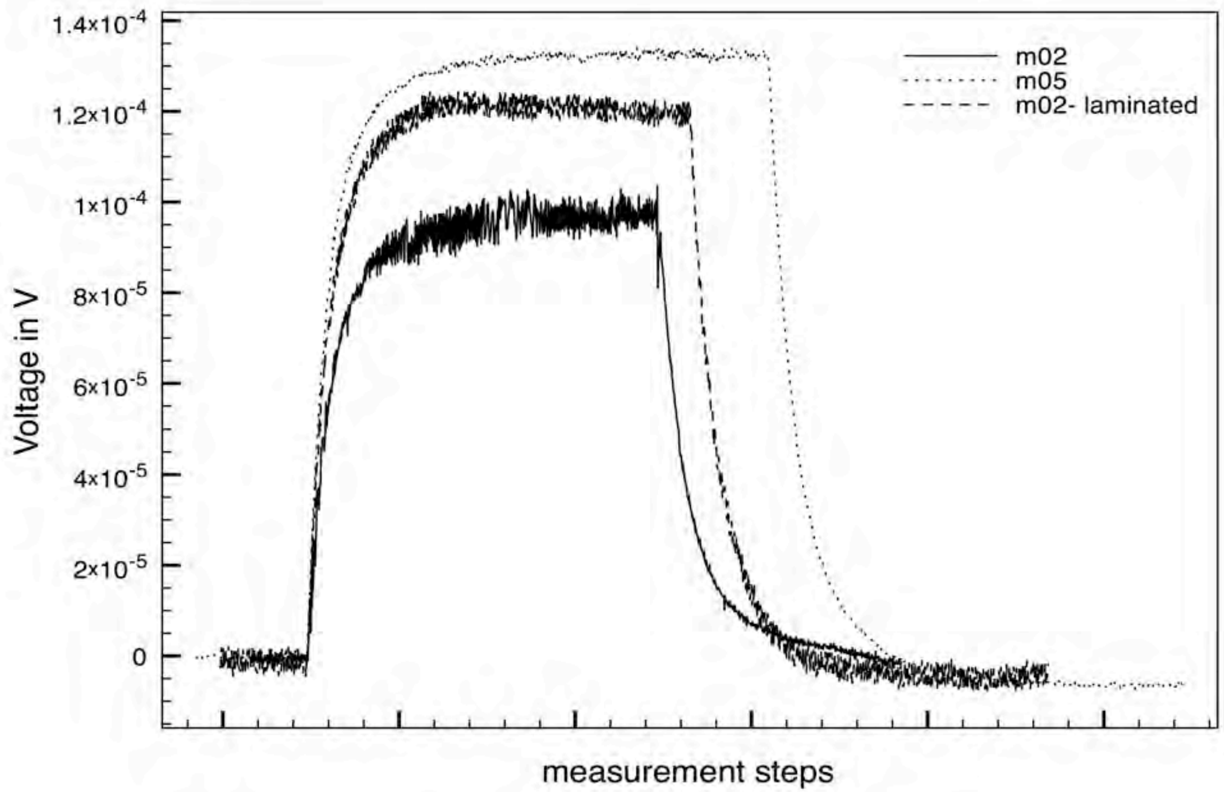
Printed Thermoelectric Generator

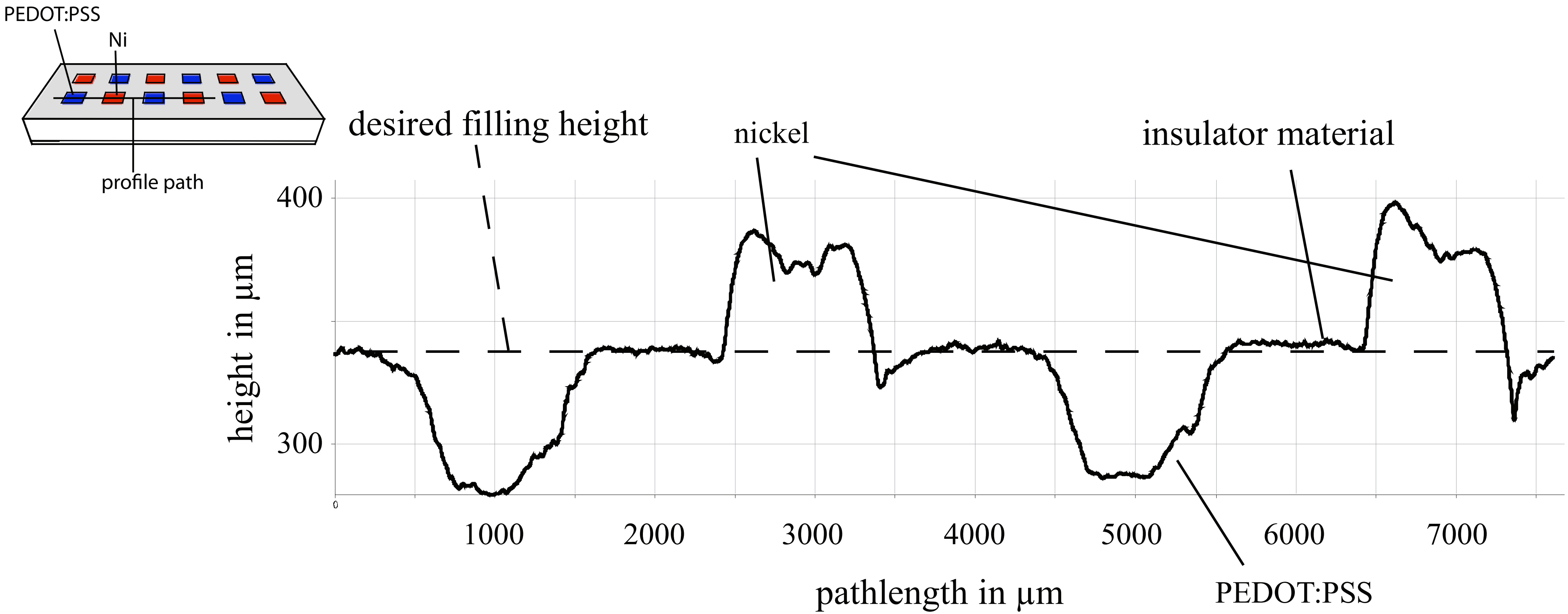


Thermoelectric potential
~120 µV

Seebeck coefficients:
- PEDOT:PSS 8 -15 µV/K
- Ni (bulk) -22.5 µV/K

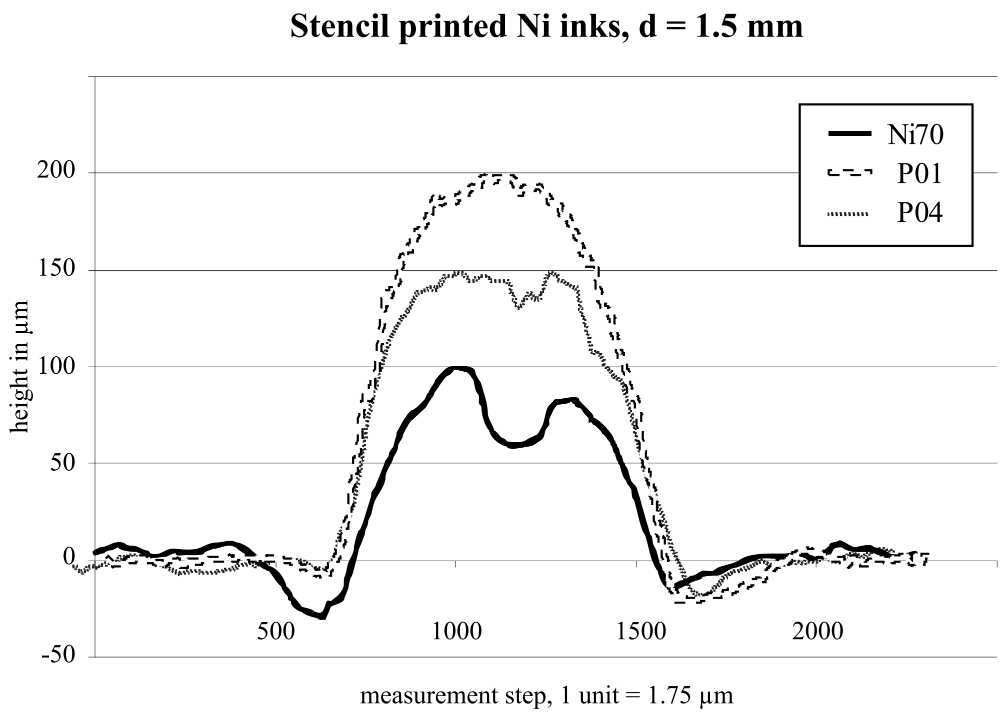
overall height ~50 µm
problem: persistent temp. gradient

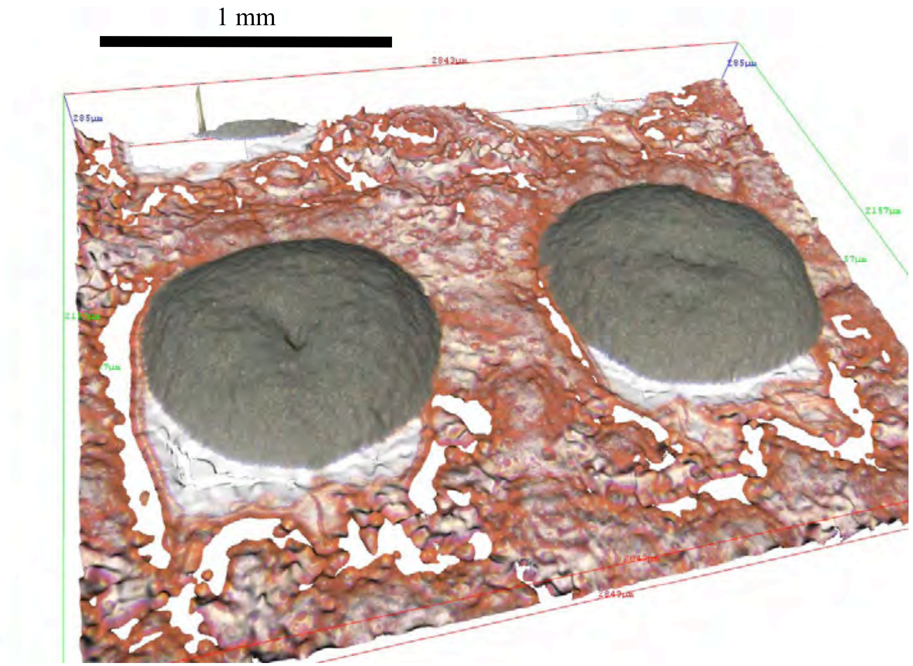
Examination of Ni-Inks



Problem: “doughnut-effect” and dome-like ink deposition

Examination of Ni-Inks





Problem: “doughnut-effect” and dome-like ink deposition

Screen printing vs. stencil printing

- First trials: 77-48 screen mesh with thick stencil (emulsion over mesh ~70 µm)
  - Poor print quality, partially filled cavities
- 2nd Approach: stencil printing

Part 2 – Ink modification

Nickel inks – first formulation Ni70

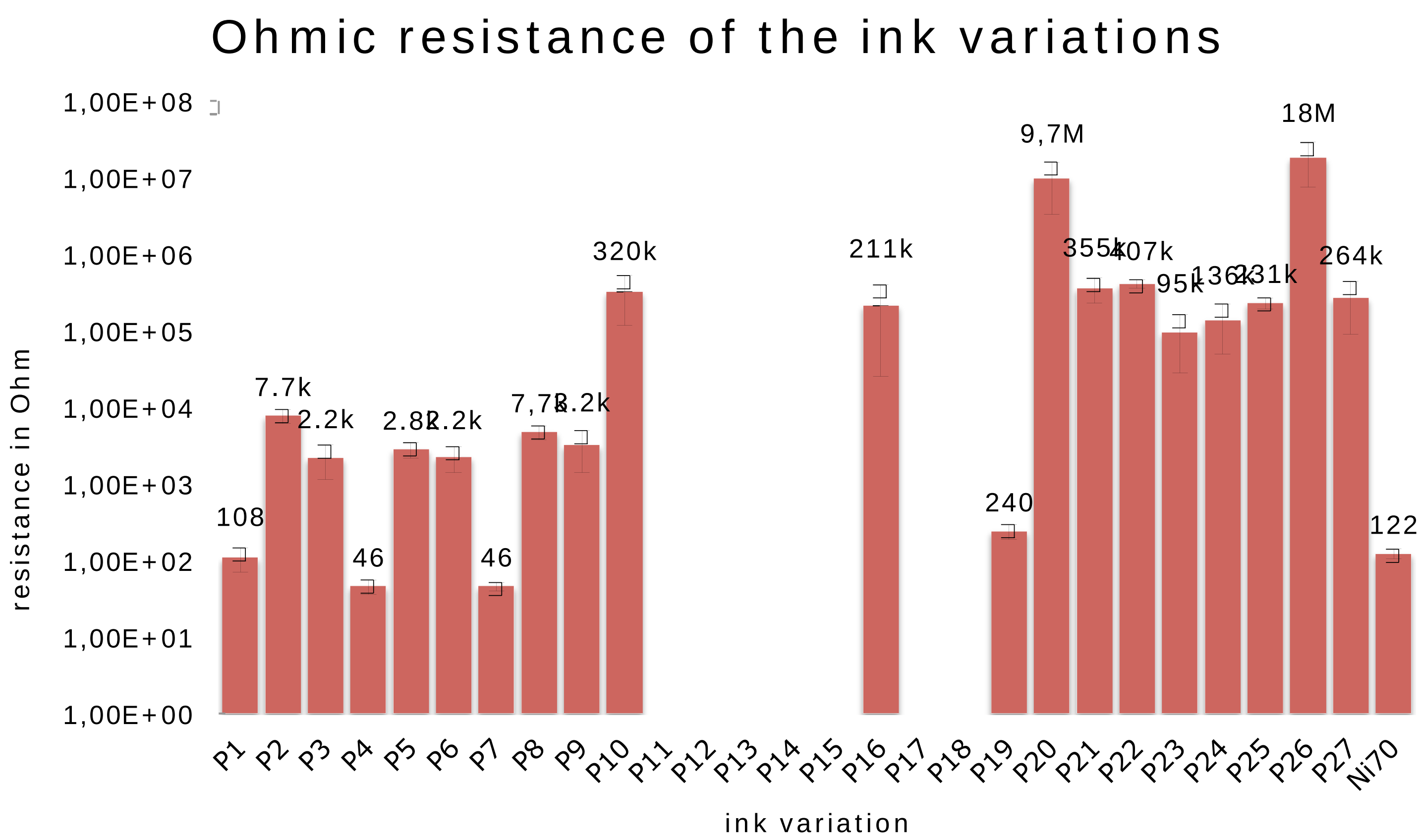
- Formulation on Alfa Aesar Nickel, Ethylcellulose and n-Butanol
- Solids 60%, Pigment volume concentration 82%
- Reasonable conductivity, bad levelling and drying properties

Nickel inks – new formulations

Parameter / Factor	Variables / Level		
Ni particles	Alfa Aesar Ni powder	Vale T255™ Ni powder	Alfa Aesar : Vale T255™ (1:1)
Particle size	3-7µm	2-3µm	blend (2-7µm)
solvent	Cyclohexanone	Cyclohexanone : Butyl glycol acetate (2.6:1)	Cyclohexanone : 2-Ethylhexyl acetate (2.6:1)
additive	no additive	DISPERBYK® 180	DISPERBYK® 2155

Solids 50%, Pigment volume concentration 80%

Nickel inks – conductivity



Nickel inks – conductivity

- Smaller particles show less resistance
- Additives increase resistance
- Unclear effect of cosolvent on resistance
- Mixture of two particles show no conductivity at all

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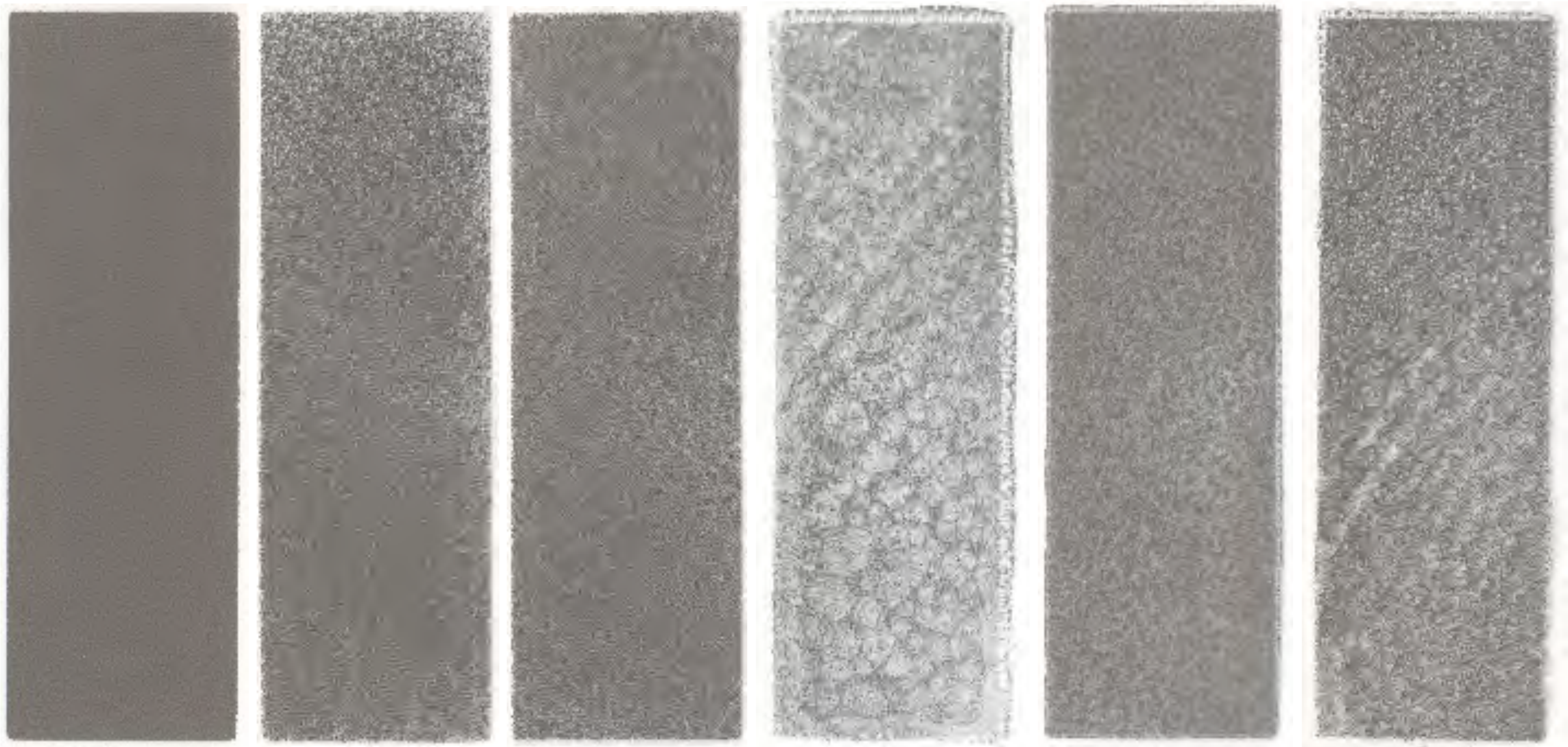
Nickel inks – conductivity



Ni70 P01 P04 P14 P16 P26

Nickel inks – conductivity

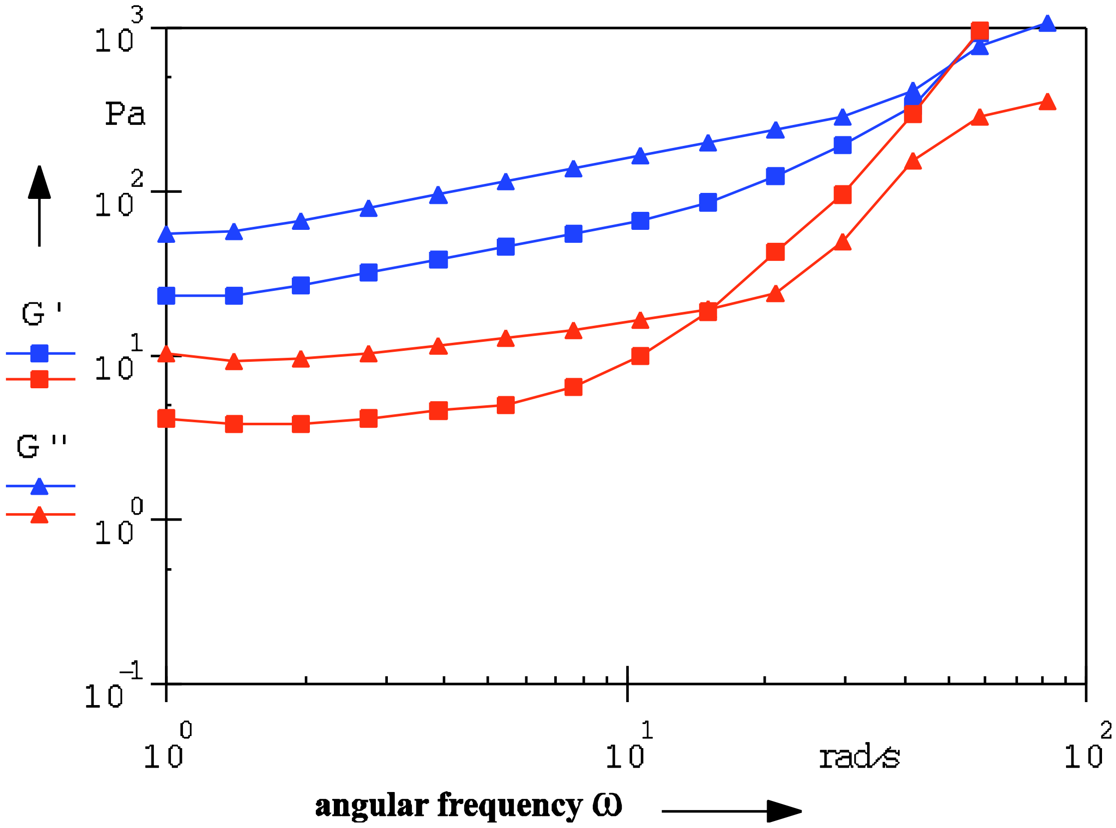
- Worse printed layer than Ni70
  - May be linked to lower solids
- Faster settling may also be linked to solids
- Optimisation necessary but promising first results

Nickel inks – rheological testing

blue Ni70, red P01

Both inks show dilatancy while the viscosity for P01 is lower

Poor transfer of P01 linked to earlier G'/G'' crossover and lower viscosity

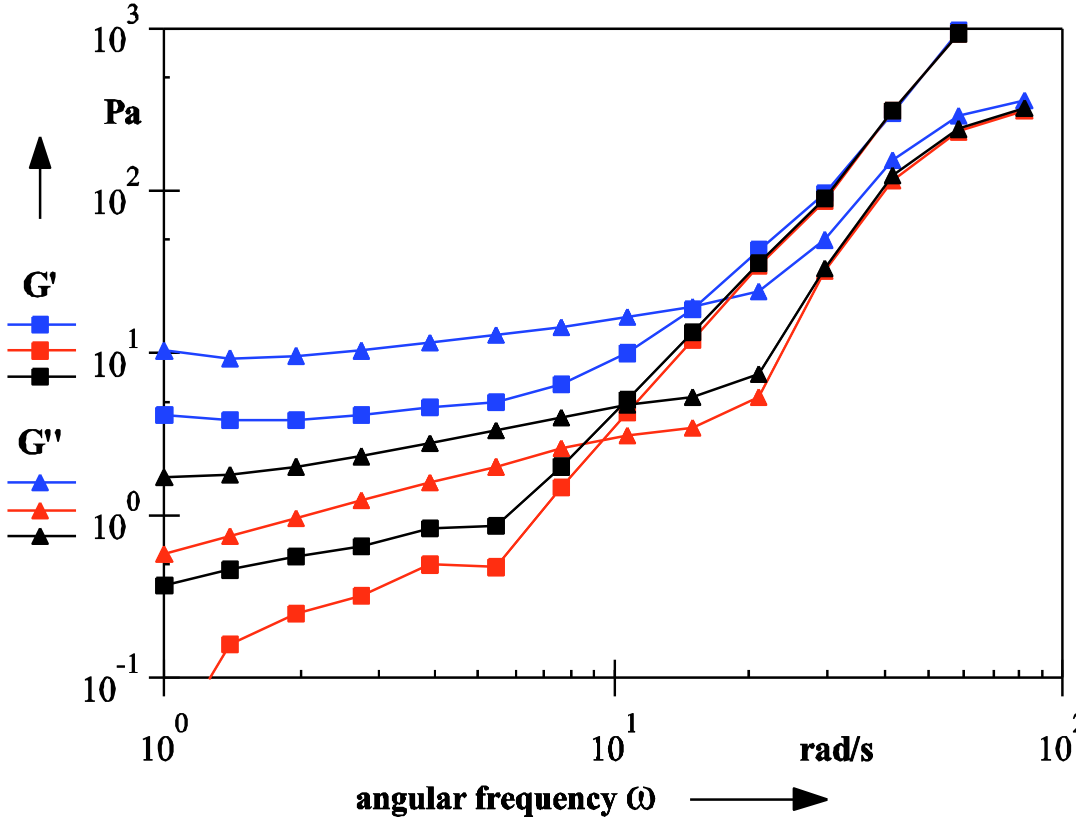


Nickel inks – rheological testing

blue P01, red P02, black P03

Clear influence of additives on viscosity

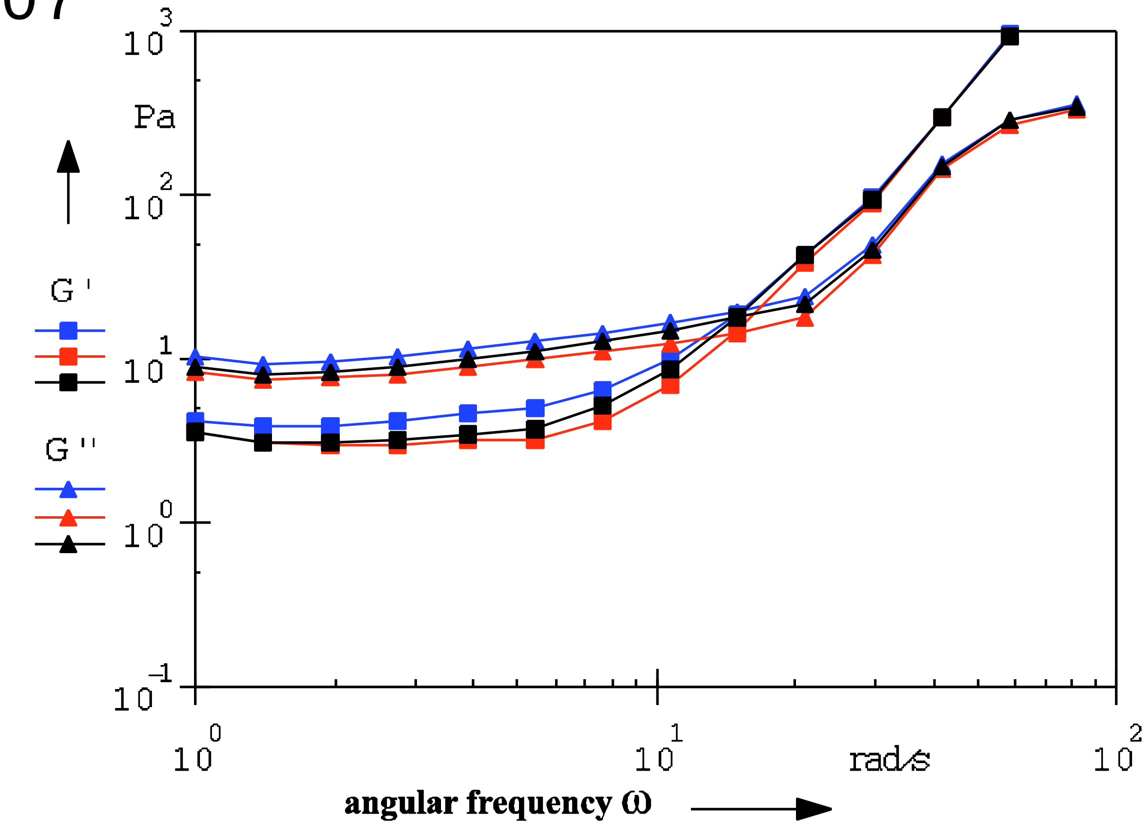
Earlier G'/G'' crossover again connected with lower viscosities



Nickel inks – rheological testing

blue P01, red P04, black P07

No influence of cosolvents on viscosity or dilatancy



Nickel inks – rheological testing

- Lower viscosity worsens dilatancy
  - Solids content should be increased
- Cosolvents do not influence viscosity
- Additives lower viscosity but also increase ohmic resistance

Conclusions

- Modification of Nickel ink formulation led to increased conductivity
- Printabilty only proved with stencil printing
- Doughnut effect was reduced
- Clogging of mesh eliminated

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Thank you!