NREL National Renewable Energy Laboratory

Innovation for Our Energy Future

Direct-Write Contacts: Metallization and Contact Formation

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Goal: Low cost Photovoltaics

How to reduce cost?

✓ Eliminate expensive processing steps
• Vacuum based thin film deposition steps
• Steps that involve patterning

✓Use less expensive materials
• Other substrates

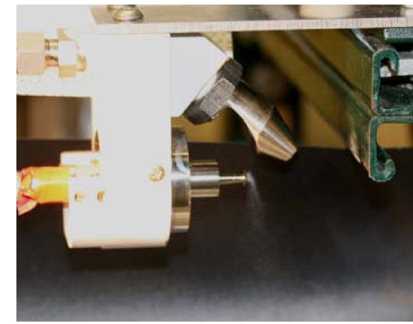
✓Reduce the amount of material used
• Reduce thickness of absorber
• Reduce or eliminate waste

→ Direct-write

Deposition Tools

Fujifilm Dimatix Materials Printer

Trident inkjet system



Sono-Tek Ultrasonic spray system

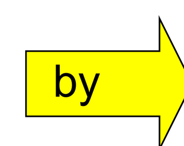
All systems:
• fully automated substrate control (X-Y)
• substrate heating

Ink Requirements for Materials Printing

Printable:
• Proper physical characteristics
• Clean formation of desired material

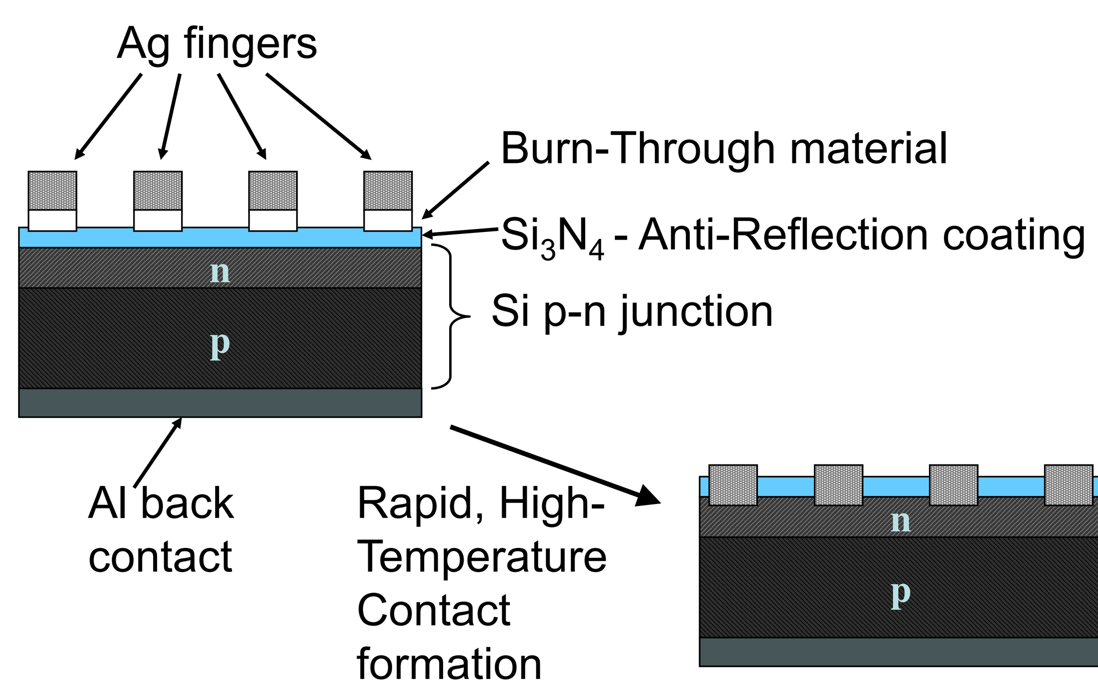
Critical parameters to be optimized:
•Electrical Properties
•Resolution
•Deposition Rate
•Adhesion
•Quality of interface

(Application specific)



Optimization of ink composition and processing parameters

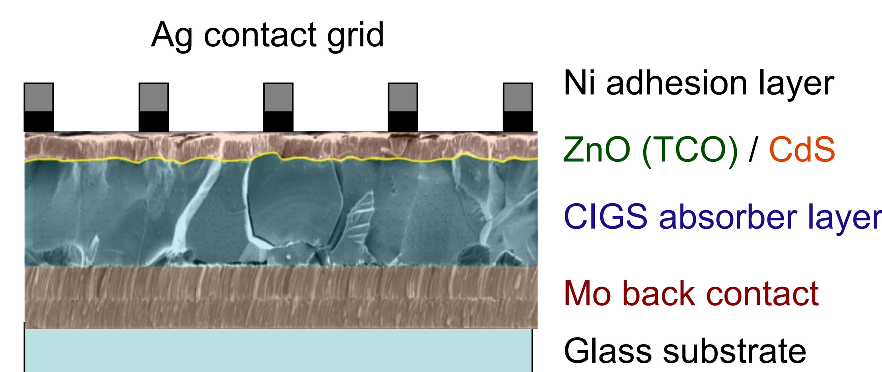
Si Solar Cell Contact Formation



Metal Contacts for CIGS

Ni Line Target:
• Uniform thin and narrow lines
• Good adhesion to substrate

Ag Line Target:
• thicker, narrow line, near bulk-material conductivity
• adhesion to Ni line



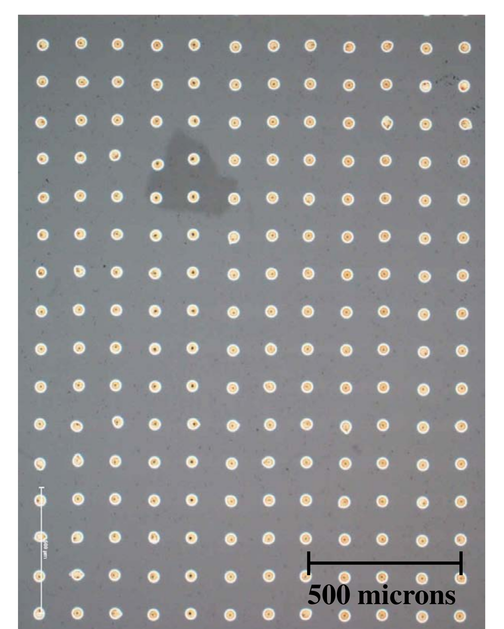
Metal Inks

Silver
Ink: MO Ag complex + solvent + surfactant ~25% Ag loading

Nickel
Ink: MO Ni complex + solvent + surfactant ~20% Ni loading

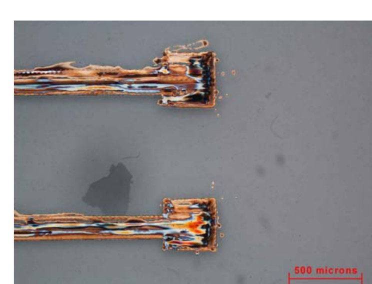
No nanoparticles!

Lines printed:
• at ~180ºC-220ºC
• in air
• no post printing processing

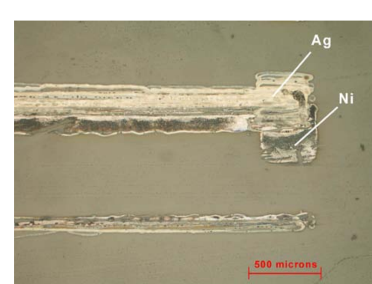


Nickel Grid

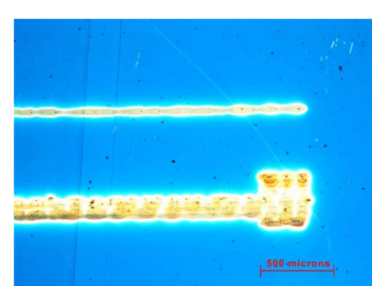
Printed Silver and Nickel



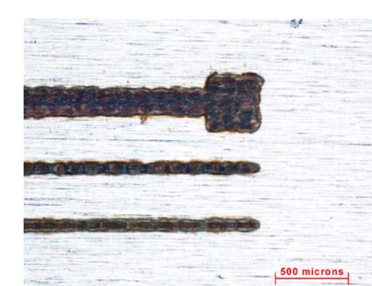
Ni on Glass



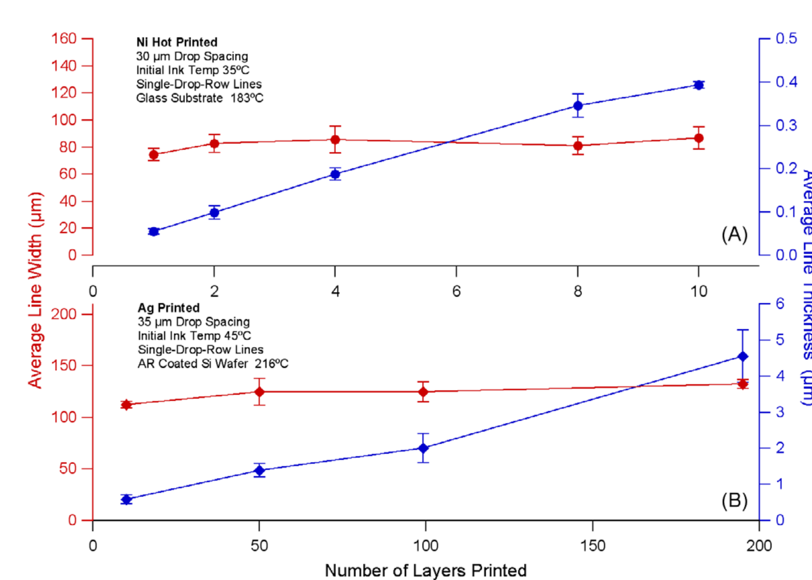
Ag on Ni Lines on Glass



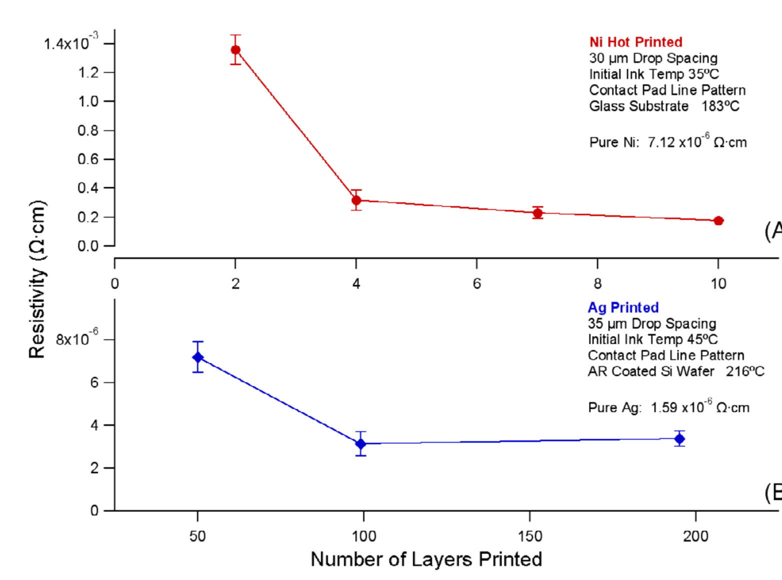
Ag on SiN_x AR Coated Si



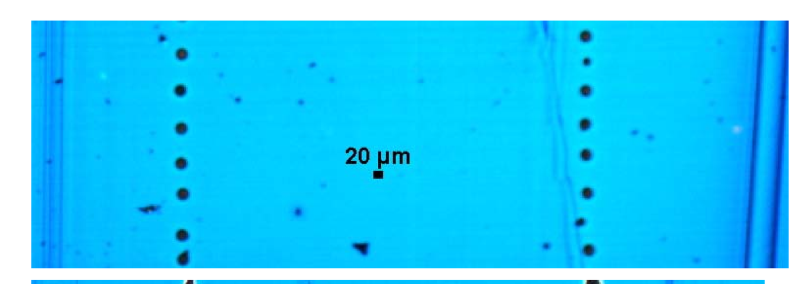
Ag on Ni Foil

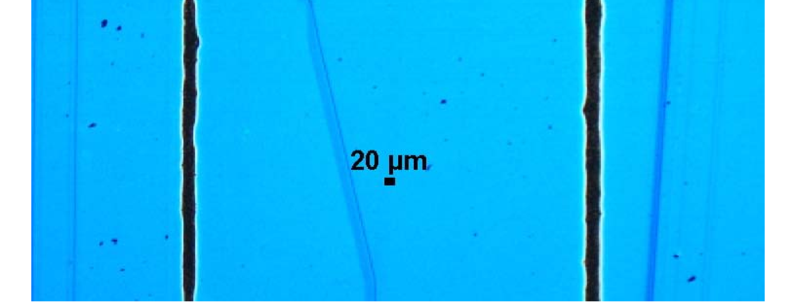


• Line width independent of number of layers
• Continuous thickness increase
• Lines <50µm wide obtained



• Best resistivity obtained for silver: 2.1 µΩ·cm
• Nickel can be improved by changing atmosphere
• Also printed copper with resistivity close to bulk



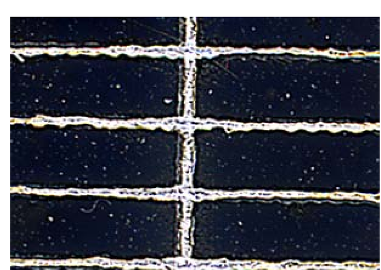


• Silver drops and lines on SiN_x coated silicon
• Drops 30 - 40 µm diameter
• Lines 30 -40 µm wide @ 10 µm thick

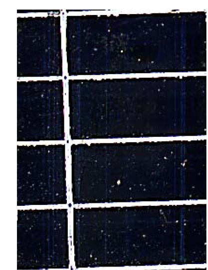
Printed Silver Contacts on Silicon

	1st	2nd	Best	Goal
Line thickness:	10 µm	15 µm	10 µm	15 µm
Line width:	400 µm	250µm	80µm	<100µm
Dep. temperature :	180°C	180°C	180°C	180°C
Ann. temperature:	850°C	850°C	750°C	<750°C
Cell efficiency	8%	8%	13%+	15%+

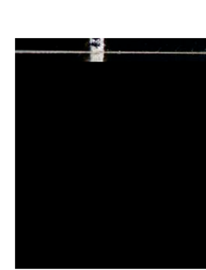
1st generation



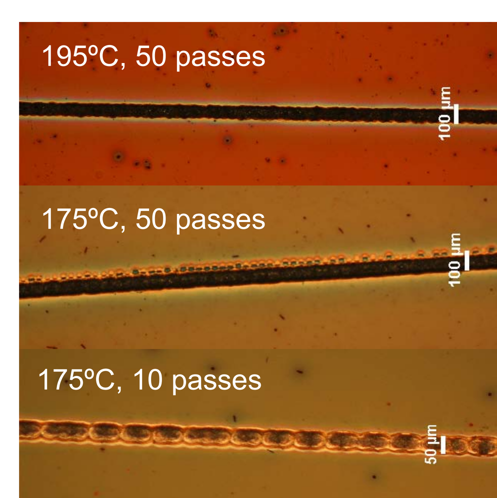
2nd generation



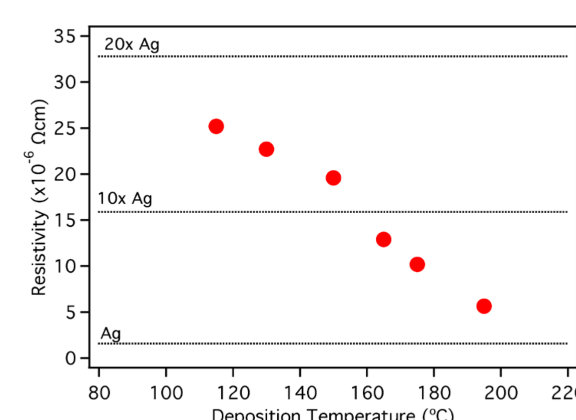
Best



Printed Silver Lines on P3HT/PCBM



Lines:
• ~5µm thick @ 50 passes
• Good resolution <100 µm
• Changed wetting vs Si



Resistivity:
• at 195 ºC good ~2x Bulk
• Increases with decreasing printing temperature
• at 160 ºC <10x Bulk

Summary

Demonstrated inkjet printing of silver and nickel
• Resistivity close to bulk
• Resolution comparable or better than screen-printing
• Low deposition temperature (<200 ºC)
• No post processing needed
• Can be printed on various substrates

Also inks available for copper and aluminum

Inks have also been developed for:
• Semiconductors:
✓ CdTe and $Cu(In,Ga)Se_2$

• Metal oxides:
✓ $Ba_xSr_{1-x}TiO_3$ (BST), ZnO, In_2O_3, IZO, SnO_2 and SiO_x

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