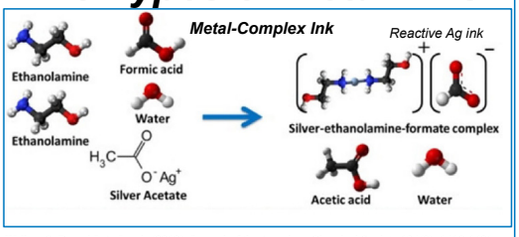
Metal-Complex Inks for Lower Cost and Improved Passivation for Silicon Photovoltaic Metallization

David L. Young[1], William Nemeth[1], Matthew Page[1], Markus Kaupa[1], Harvey Guthrey[1], San Theingi[1], Melbs LeMieux[2]

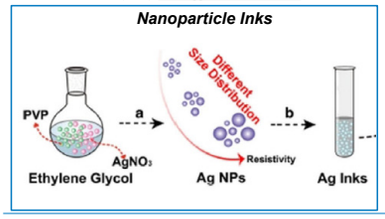
[1]National Renewable Energy Laboratory, Golden, Colorado 80401 USA

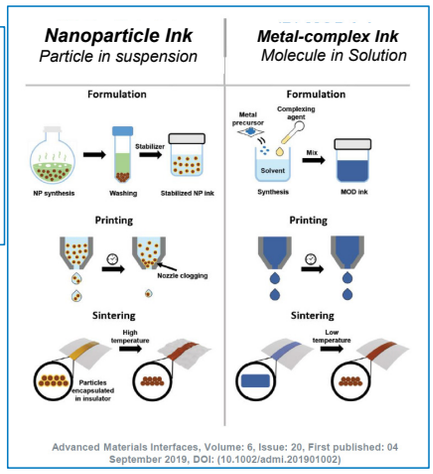
[2]ElectronInks, Inc, Austin, Texas 78744 USA

Two Types of Metal Inks



Walker, S. B. and J. A. Lewis (2012). Journal of the American Chemical Society 134(3): 1419-1421
Eva S. Rosker, et al., (2020). ACS Appl. Mater. Interfaces 12: 29684−29691





Advanced Materials Interfaces, Volume: 6, Issue: 20, First published: 04 September 2019, DOI: (10.1002/admi.201901002)

What are Metal-Complex Inks?

- New class of non-particle based inks
- Metals are suspended in solution as cations
- Metals "precipitate" out to form continuous metallic films upon annealing at low temperatures

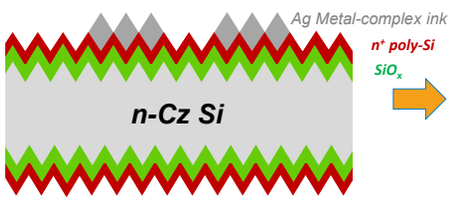
What are the benefits?

- Dense films (up to 93% of bulk metal)
- High conductivity (up to 80-90% of bulk metal)
- Screen printable
- Ink Jet compatible with no particle clogging
- Low annealing temps (160 ˚C – 300 ˚C)
- Compared with particle-based pastes:
  - 22% less Ag
  - 33% less cost

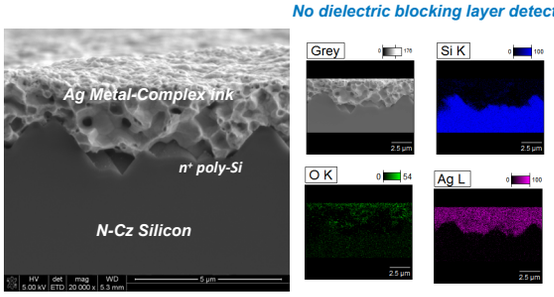
Initial Tests on PV Surfaces

Poly-Si/SiO_2 Contacts

Non-optimum screen-printed Ag Metal-Complex Ink
Annealed in air 160 ˚C -> 300 ˚C



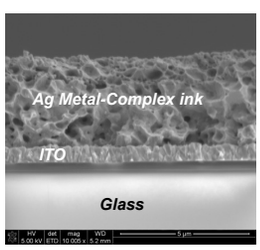
No dielectric blocking layer detected



- HF etch prior to printing
- Good screen printing fidelity
- Dense honeycomb-like metal film, but still quite porous
- Low recombination: $J_{o\_metal} \sim J_{o\_field}$
- Poor contact resistivity: Ohmic, but very high resistance

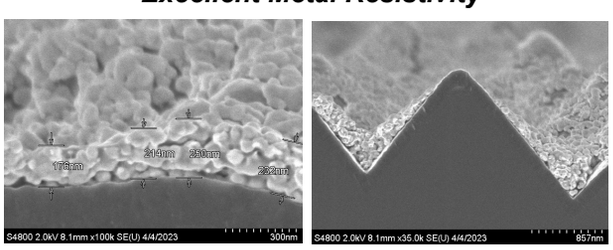
TCO Contacts

- Good adhesion to TCO
- Low contact resistivity to ITO

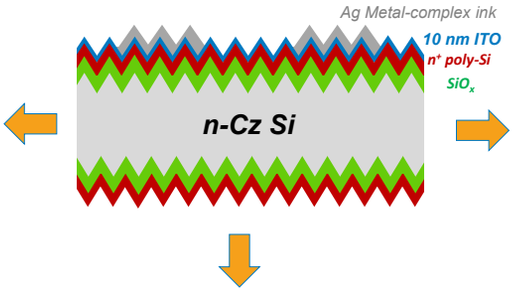


ITO (10 nm)/Poly-Si/SiO_2 contacts

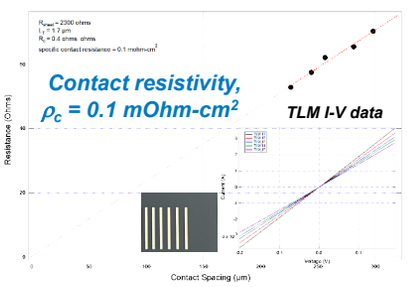
Excellent Metal Resistivity



- Thin metallic layers 175 nm – 250 nm
- ρ_{metal} = 3-7E-8 Ohm-m (~2-4 x ρ_{Ag})
- non-uniform coverage especially over the pyramid tips



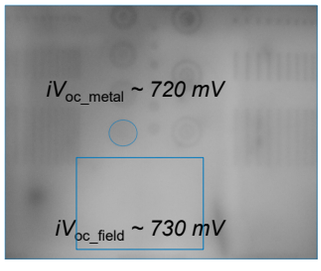
Excellent Contact Resistivity



Excellent Passivation Preservation

- The metal-complex inks do not aggressively etch the poly-Si surface
- The low-temperature annealing conditions preserve the field passivation (< 300 ˚C)
- J_o is preserved under the metal
- J_o is preserved in the field region
- $J_{o\_metal} - J_{o\_non\text{-}metal} < 1$ fA/cm²

Photoluminescence Image (1/20 s)



Conclusions:

- Metal-complex inks are a promising new path for PV contacts to lower cost, Ag usage and improve passivation.
- Dense, thin films
- High metallic conductivity
- Low contact resistivity
- High passivation preservation under the metal
- Low-temperature anneal (preserves J_{o_field})
- Need to improve screen-printing uniformity
- Need to improve direct contact to Poly-Si
- Cu-based metal-complex inks are under development

This work was authored in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

Post Doc Wanted!

Interested in a post doc at NREL? We are looking for a post doc with experience in metallization to continue this study using Cu-based metal-complex inks. Contact Dr. David Young for more information.

David.young@nrel.gov

SiliconPV 2023
Delft, The Netherlands
April 10 – 14, 2023
NREL/PO-5900-85313