SOUTH DAKOTA SCHOOL OF MINES & TECHNOLOGY
UNIVERSITY OF SOUTH DAKOTA

Printing and photosintering silver nanoparticle ink on paper for antenna and security applications

Sierra Rasmussen: Missouri University of Science & Technology
Faculty Advisors: Dr. Grant Crawford, Dr. Jon Kellar, Dr. William Cross, Dr. Alfred Boysen
SDSU South Dakota State University
MISSOURI S&T University of Science & Technology

Introduction

Silver nanoparticles suspended in toluene can be printed as an ink and then cured with a sintering process to create continuous layers of conductive silver. These layers of silver can then be used in electronic applications, including printed antennas. By using photonic sintering rather than thermal sintering, it will be possible to create conductive layers on material that can be easily damaged by high heat, such as paper.

Silver nanoparticle (Ag NP) attributes:
- ~4-7 nm diameter
- Lower melting point than bulk silver

Ag NP ink:
- Ag NPs suspended in toluene
- 65-75 wt% Ag NPs

Photonic Sintering Background:
- Novacentrix Pulseforge
- Thermal processing using pulses of high-intensity white light
- Variable voltage and time settings

Figure 1: QR code antenna pattern for printing on paper.

Procedure

Silver NP Synthesis + Ink Preparation [1]

1. Dissolve $AgNO_3$ in n-Butylamine
2. Dissolve decanoic acid in toluene
3. Add decanoic acid and toluene solution to $AgNO_3$ and n-butylamine solution
4. Add $NaBH_4$ to mixture, heat to ~80°C
5. Reflux 1 hour
6. Clean particles with acetone and methanol, filter using Erlenmeyer flask and Buchner funnel
7. Dry in petri dishes, redisperse in toluene
8. Vortex, Sonicate, & Centrifuge to suspend small particles and make larger particles settle
9. Deposit 100 µL into empty glass vial and evaporate to determine wt% of Ag NPs in ink

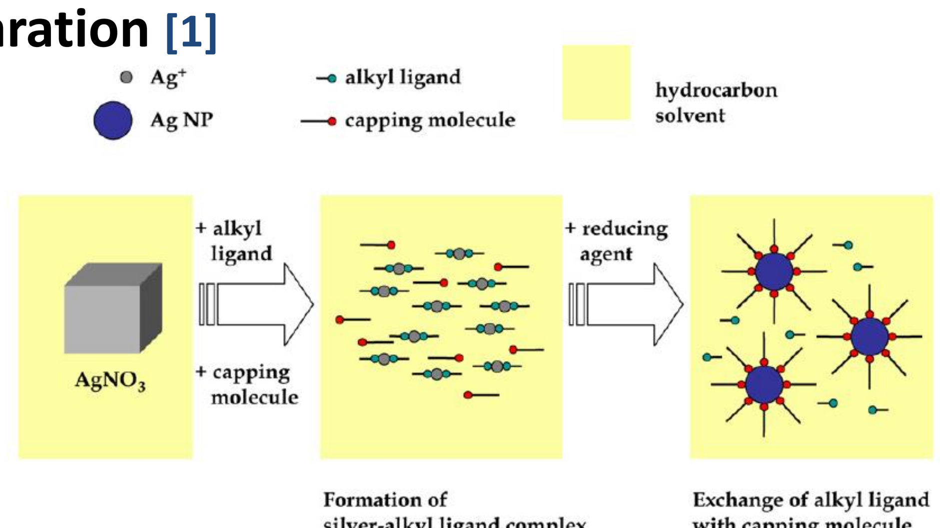

Figure 1: Silver NP Synthesis (Diagram from [2])

Printing
- Optomec M3D, 300 µm orifice
- Print 10 mm x 1 mm Microstrips and 3 cm x 3 cm QR codes

Curing
- Thermal: Heated in oven at 200°C for 2 hrs
- Photonic: 800-1200 V for 500-900 µm

Broader Impact

- Electronic applications
- Security applications
    - Antenna
- Faster sintering in industry

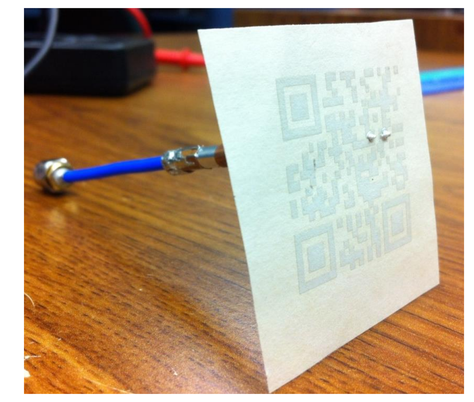

Figure 2: Printed antenna wired for testing.

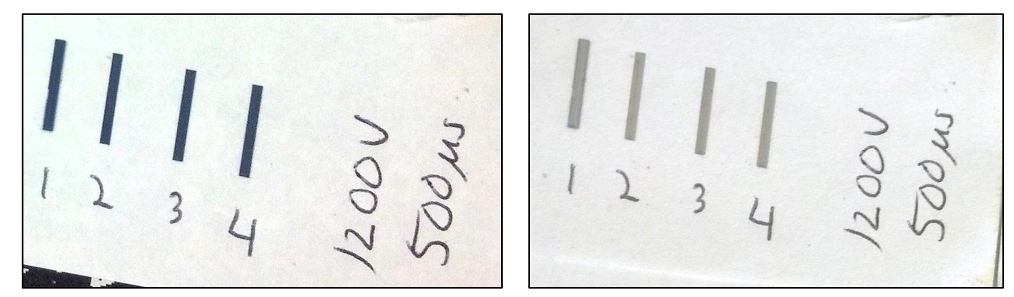

Figure 3: Samples before (left) and after (right) sintering.

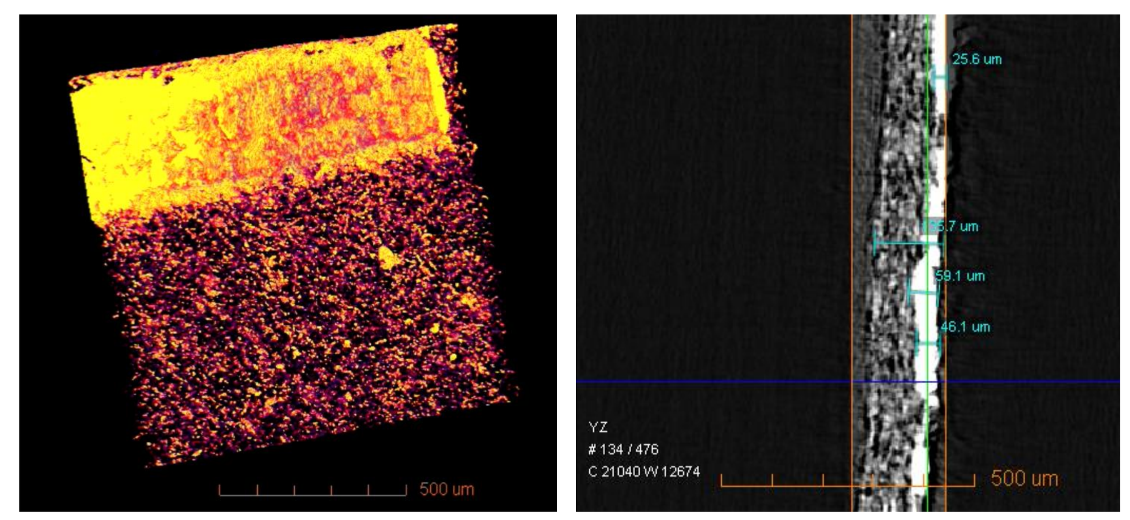

Figure 4: MicroXCT image of sample and MicroXCT image showing sample thickness

Results

Sintering parameters	Material	Average thickness	Conductivity
Thermally sintered	linen	51.46 µm	0.049 /Ωm
Thermally sintered	paper	11.87 µm	0.527 /Ωm
1200 V 900 µs	linen	17.967 µm	0.501 /Ωm
1100 V 900 µs	linen	10.843 µm	0.441 /Ωm
1200 V 700 µs	linen	9.78 µm	1.504 /Ωm
1200 V 600 µs	linen	5.84 µm	0.682 /Ωm
1200 V 500 µs	linen	20.89 µm	0.076 /Ωm
1200 V 900 µs	paper	9.04 µm	0.930 /Ωm
1200 V 700 µs	paper	3.83 µm	1.070 /Ωm

Table 1: Showing differences in print thickness, conductivity, as related to different sintering parameters.

Figure 5: Resonance coefficient of thermally sintered antenna, resonating at 2.4 GHz

Figure 6: Resonance coefficient of photo-sintered antenna, resonating at 2.4 GHz

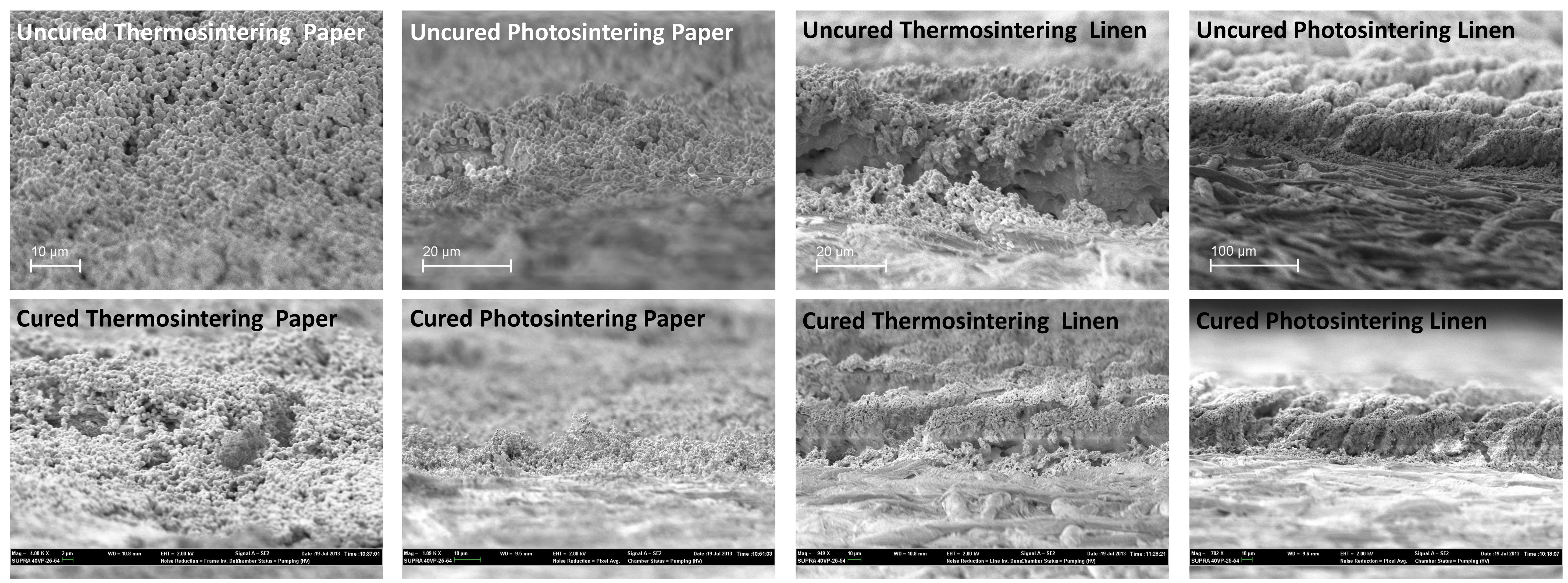

Figure 7: SEM of paper and linen samples before and after sintering, showing effects of sintering on samples.

Conclusions

Photonically sintered silver nanoparticle ink on paper demonstrates sufficient conductivity for antenna applications, with minimal alteration to the substrate. Conductivity on paper also seemed to be twice as high as on linen.

Future Work

Future experimentation will be inclusive of improved ink adhesion to the substrate. Possible solutions include a thin polymer coating over the deposition or use of thermally-assisted photosintering to more thoroughly sinter the underlying material.

Acknowledgments:
This work was made possible by the National Science Foundation REU Security Printing and Anti-Counterfeiting Site EEC-1263343
Special thanks to Dr. William Cross, Dr. Jon Kellar, James Randle, and to graduate students Jacob Petersen, Jeevan Meruga, Abu Numan-Al-Mobin, and Krishnamraju Ankireddy for help and guidance.
The micro-computed tomography equipment used in this research was purchased through NSF Grant #CMMI-1126848.

[1]: Ankireddy, K., Vunnam, S., Kellar, J., & Cross, W. (2013). Highly conductive short chain carboxylic acid encapsulated silver nanoparticle based inks for direct write technology applications. *Journal of Materials Chemistry C, 1*, 572-. doi: 10.1039/c2tc00336h
[2]: Carter, M., Sears, J., Smith, S., & West, J. (2012). Photonic sintering of silver nanoparticles: Comparison of experiment and theory. In V. Shatokha (Ed.), ***Sintering - Methods and Products.***