SNM 1246715: A Versatile Microplasma-based Patterning Technology for Large-Scale, High Throughput Nanomanufacturing

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Project Objectives:

(1) To develop a direct-write alternative to conventional 2D printing and subtractive photo/electron beam lithography that is suitable for the fabrication of micro and nanosystems on polymer substrates and inherently adaptable to roll-to-roll processing

(2) To develop polymer substrates with significantly improved moisture barrier characteristics for use in flexible electronics applications

Technical Barriers to Broad Implementation of Flexible Electronics

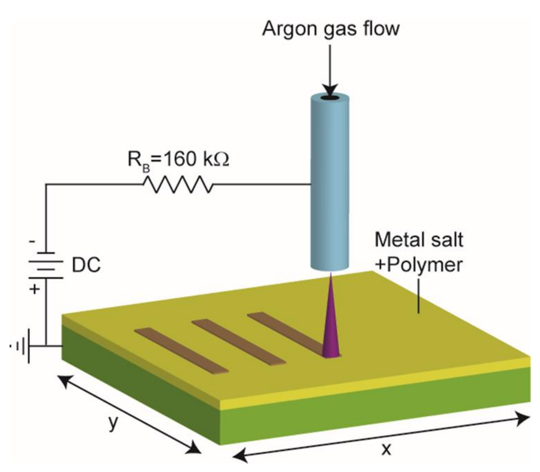
- Conventional 2D printing and utilizes inks that require post-print processing (i.e., annealing) to form conducting structures, thus limiting the selection of both substrate and ink. Moreover, 2D printing cannot be used to fabricate structures with submicron dimensions
- Leading nanofabrication techniques such as electron beam lithography and extreme UV lithography are not suitable for high throughput production because such systems are extremely expensive and difficult to implement in roll-to-roll processing
- Conventional polymer materials used in flexible electronics are either not well suited for extended use in high moisture environments (ie., polyimide) or not compatible with roll-to-roll processing (i.e., parylene).

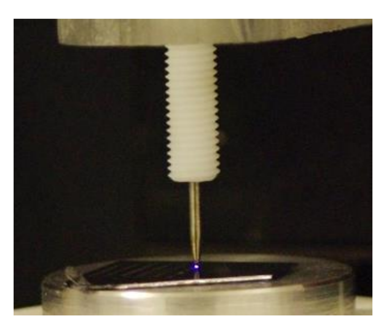
To address these barriers, this project focuses on the following:

- Robust, direct writing techniques based on novel *atmospheric pressure-based microplasmas* are being developed to realize large area patterns of metallic nanostructures under ambient conditions with features down to sub 100 nm when used with nanostencils. Approaches currently under development include: (1) electrochemical reduction of metal ions by plasma electrons, and (2) microplasma-enabled sputtering. Use of atmospheric pressure makes these approached inherently scalable to roll-to-roll processing.
- Nanolayered polymer substrates that exhibits moisture barrier properties suitable for flexible electronics, scalable to roll-to-roll processing and compatible with our microplasma techniques are being developed.

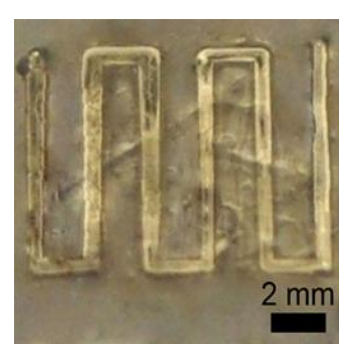
Microplasma-based Patterning by Electron-based Reduction

We have developed an atmospheric pressure DC plasma,direct-write maskless patterning process that uses electron reduction of metal ions in a polymer matrix.

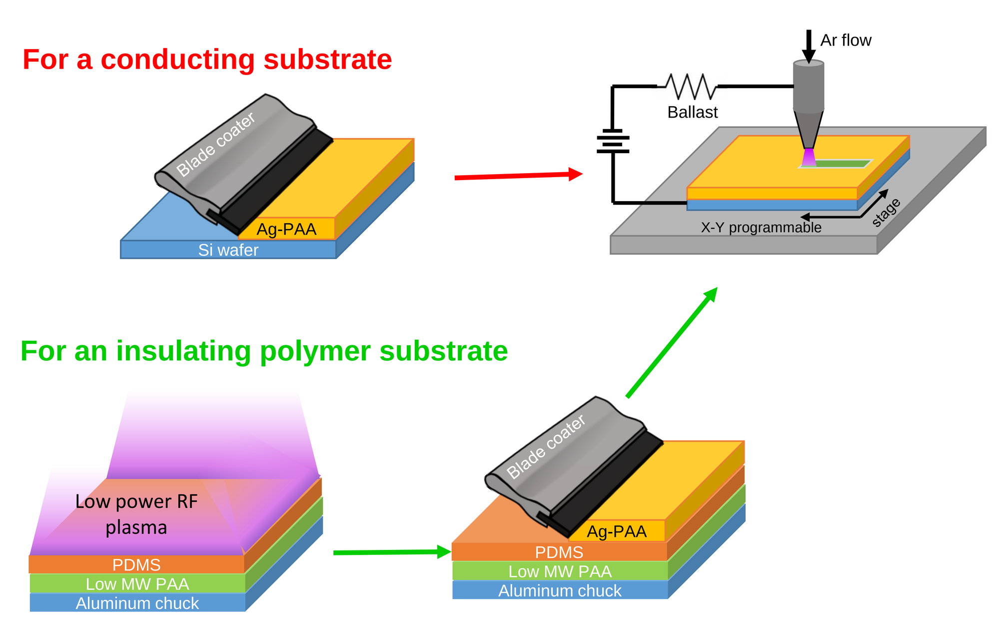




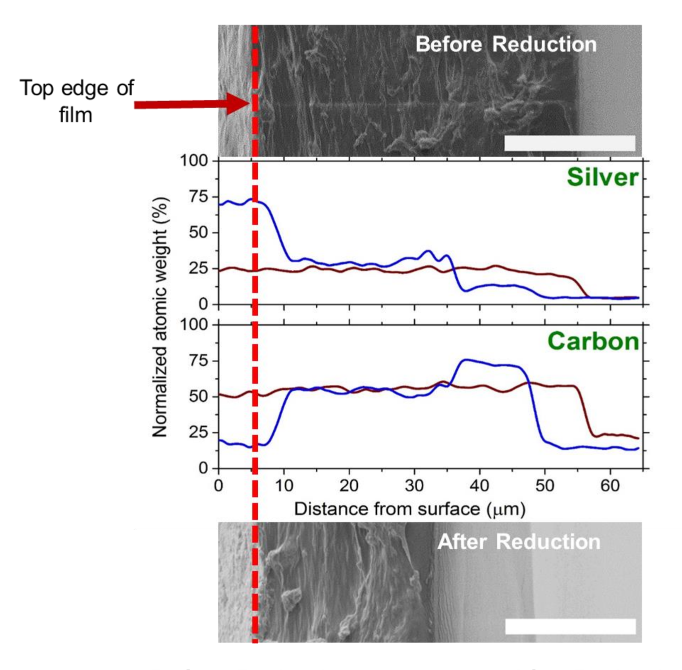
Optical Image of the atmospheric pressure DC plasma on a Si substrate



Fabrication of Flexible & Stretchable Conductors

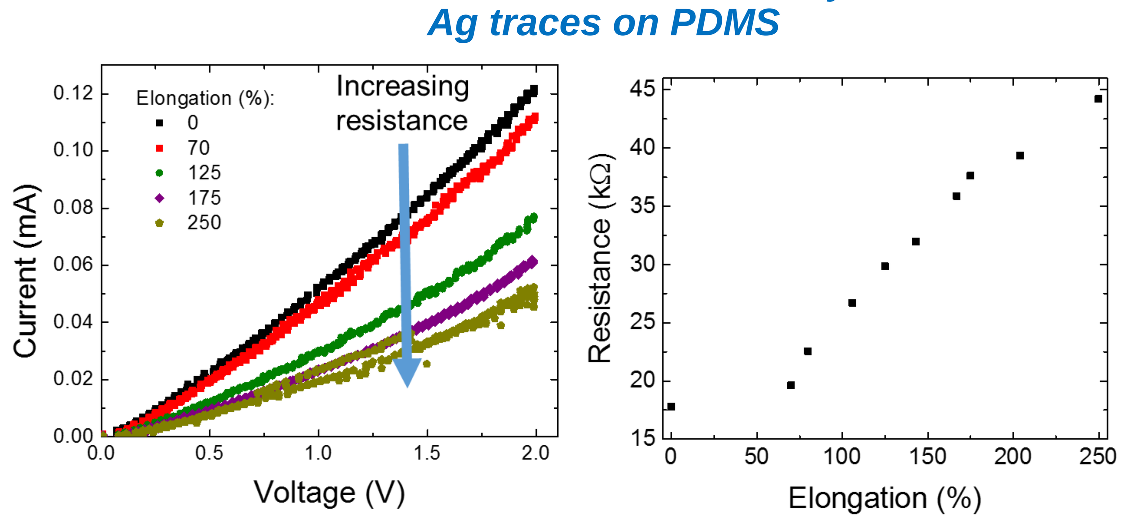


Cross-sectional SEM and EDX Analysis

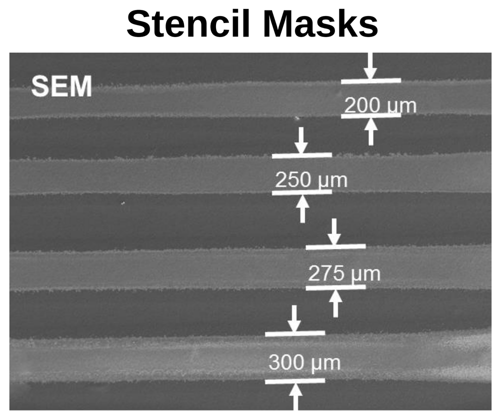


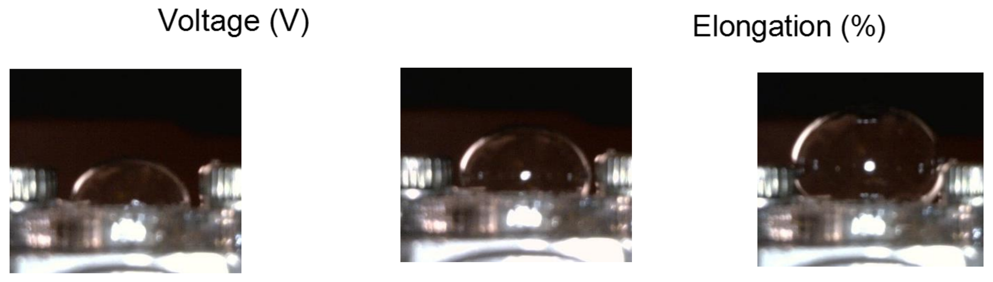
Ag structures written into Ag;PAA on PDMS

I-V measurements of mechanically-loaded Ag traces on PDMS



Pattern Transfer Using Stencil Masks

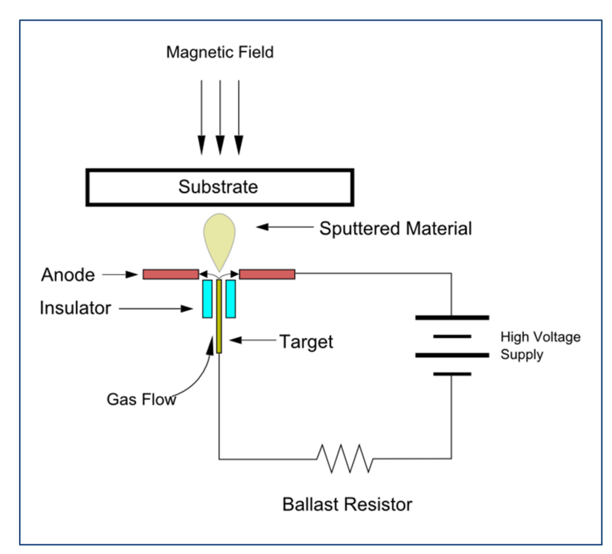


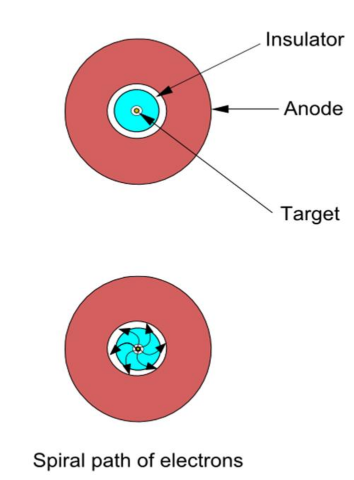


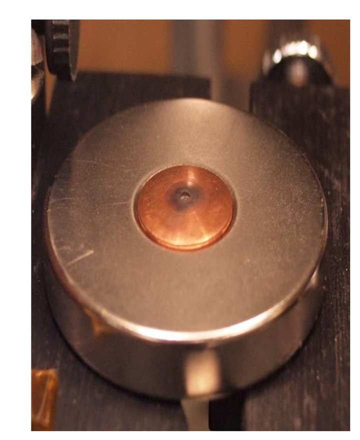
26 mm/125% 30 mm/175% 36 mm/250%

Direct-write Microplasma, Open Air Sputtering

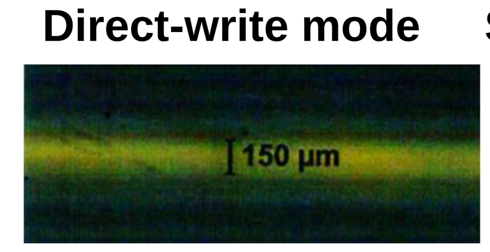
We have developed a microplasma sputtering process that leverages the advantages of conventional sputtering and ink-jet printing.

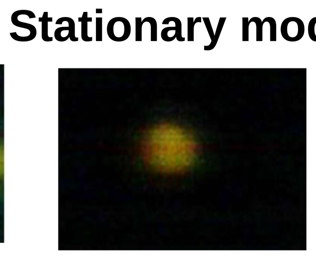






Direct-write mode **Stationary mode**

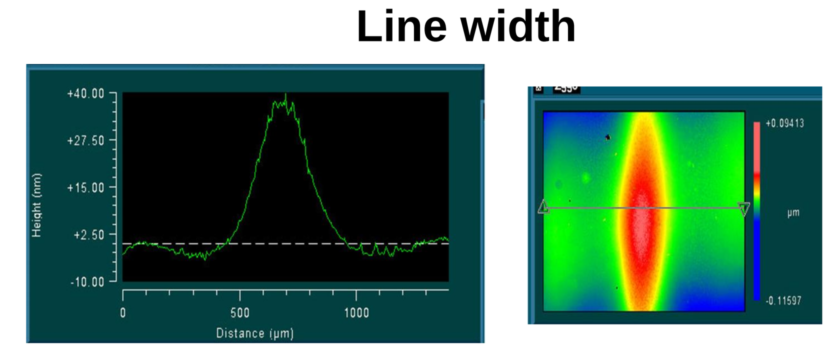


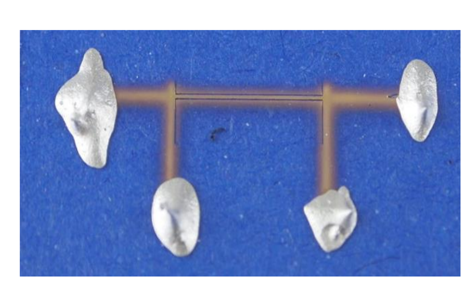


Fabrication Details:

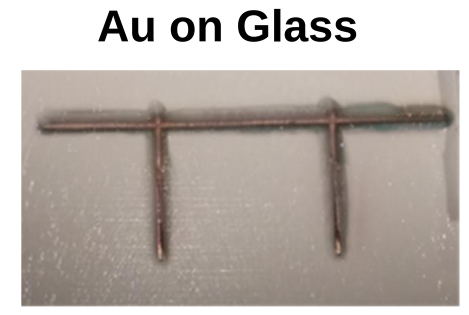
- Designed for 4-point resistance measurements
- Structure consists of 3 lines
- 9 passes per line
- Sputter Target: 75 μm-dia Au wire
- Ar flow rate: 20 sccm
- Current: ~ 5 mA
- Supply voltage: 2.5kV
- Contacts: Ag epoxy
- Writing rate: 250μm/min.
- Thickness: 40 nm

Line width

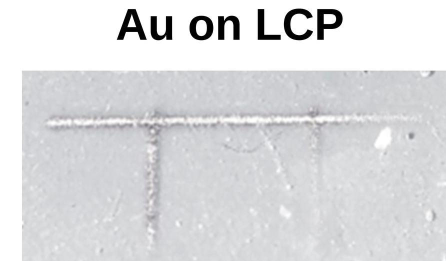




Au on Glass



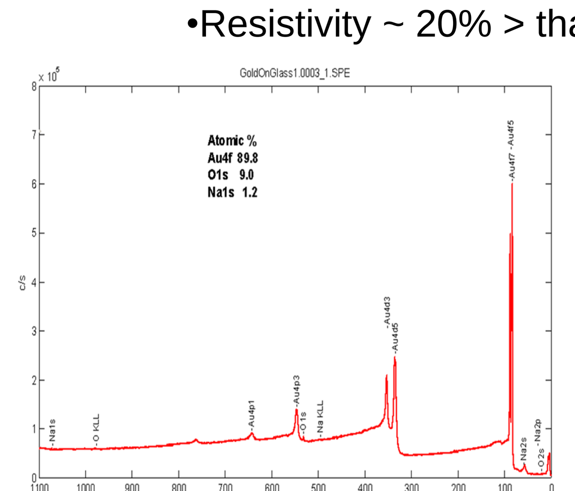
Au on LCP



Au on PDMS

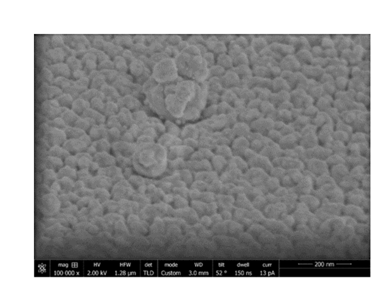
Characteristics:

- Thickness: ~ 40 nm
- Trace width: 140 μm
- Trace length: 7.6 mm
- Measured resistance: 51Ω
- Calculated resistivity: 2.67×10^{-8} Ω*m
- Resistivity ~ 20% > than bulk gold



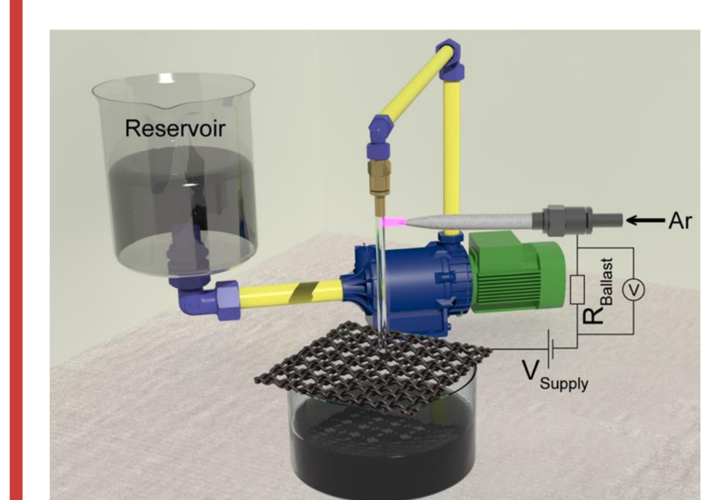
XPS analysis

SEM of sputter deposited surface



Microplasma-synthesized Nanoparticle-based Inks

We have developed a liquid water jet system for continuous synthesis of nanoparticle-based inks using a plasma-liquid chemistry



System Schematic

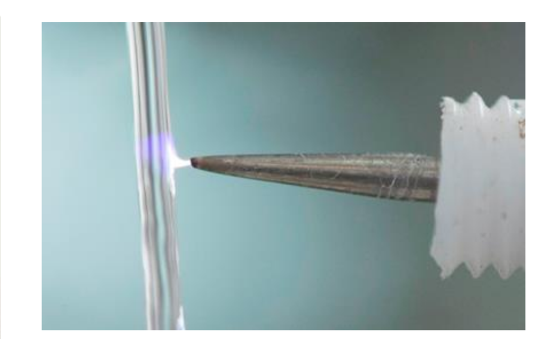
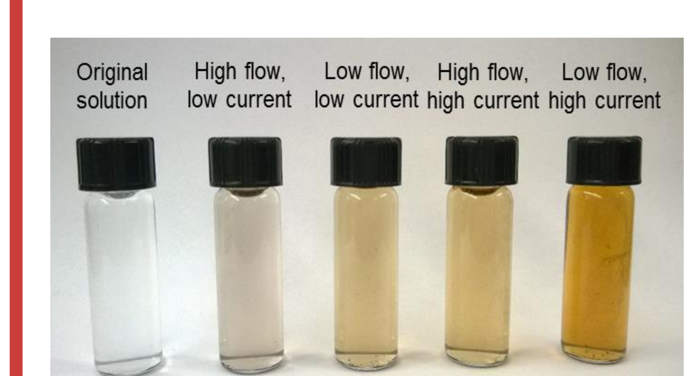
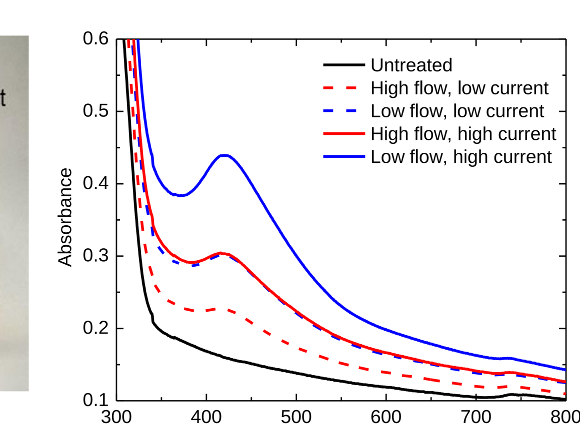


Photo of microplasma formed at the surface of a water jet

Production rate: ~ 10- 20 mL/min



Ag nanoparticle solutions capped by PAA synthesized in the liquid water jet setup at different water jet flow rates and microplasma currents.



UV-visible absorbance spectra of aqueous solutions of Ag nanoparticles capped by PAA.

TEM analysis of Ag nanoparticles

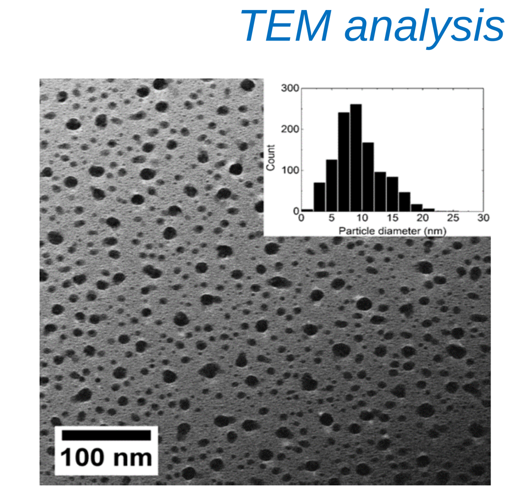
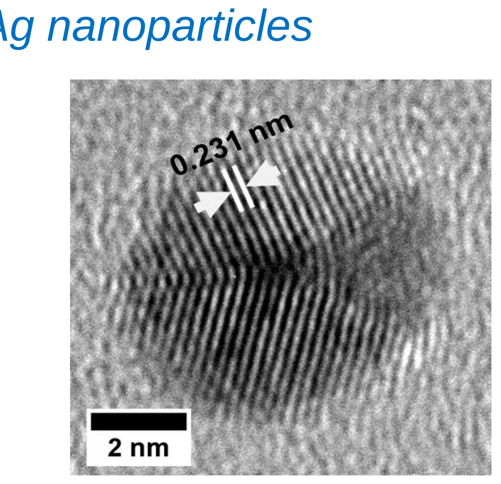


Image of Ag nanoparticles capped by PAA. Inset is a histogram of the nanoparticle diameter.



High resolution image of a nanoparticle exhibiting lattice spacings corresponding to the Ag (111) plane