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High resolution meandering metal patterns enabled by nano-bridge stencil

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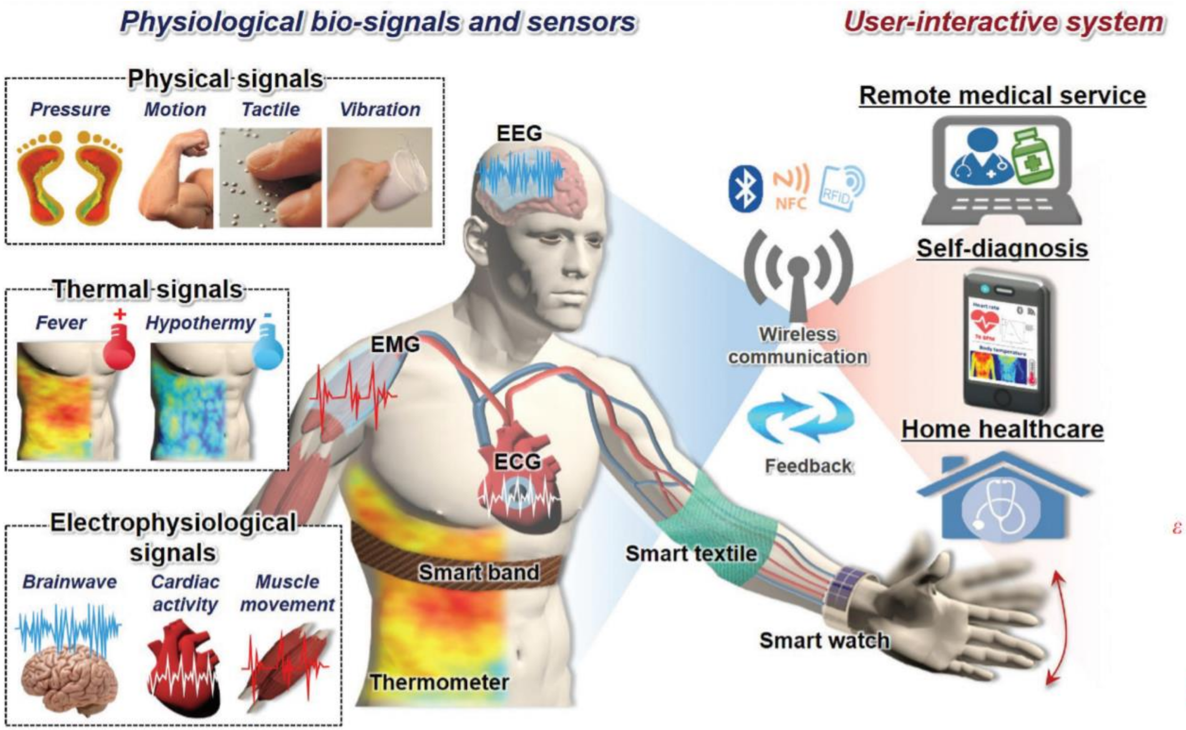
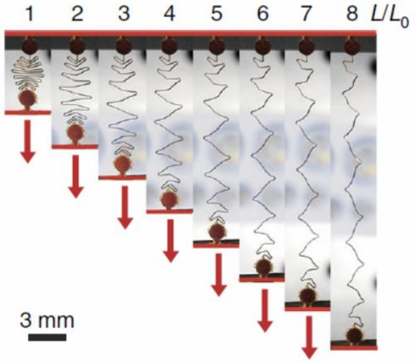
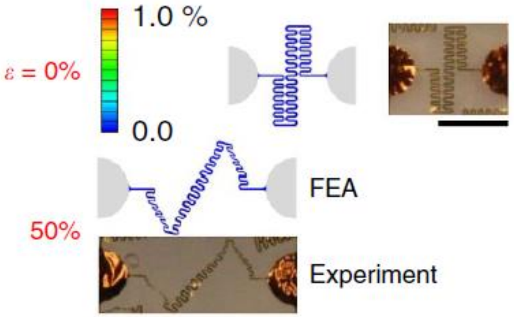
Introduction – flexible and stretchable conductors



M. Ha et al., *J. Mater. Chem. B*, 2018, 6, 4043



Q. Hua et al., *Nat. Commun.*, 2018, 9, 244



S. Xu et al., *Nat Commun.*, 2013, 4, 1543

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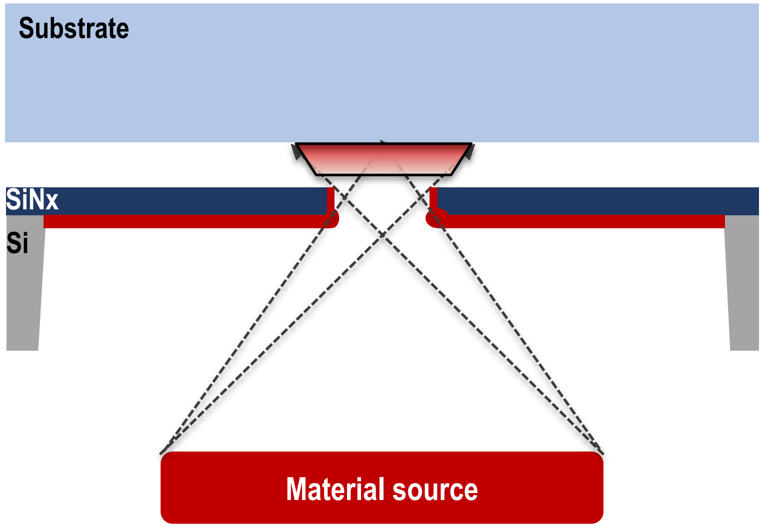
Introduction – stencil lithography

- Operation principle: locally define flux of atoms or molecules onto a substrate



Advantages

- Resistless process
- Easy manipulation and implementation
- Reusability of stencils
- Dynamic mode for multi-material structures

Challenges

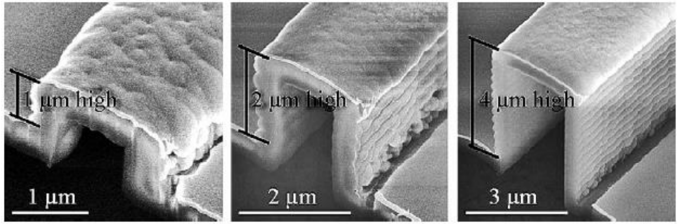
- Blurring → pattern enlargement
  - Reducing gap b/t substrate and stencil
- Clogging (aperture vs. deposition thickness)
  - Post-etching on the used stencil
- Membrane stability (aperture vs. membrane thickness)

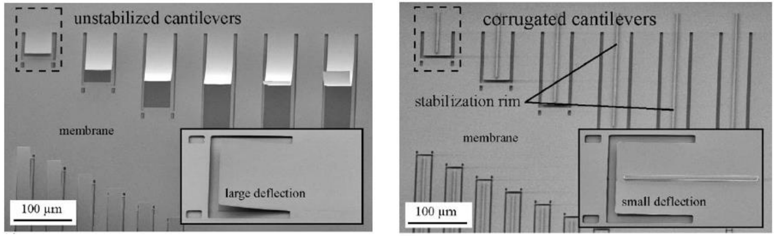
State-of-the-art – membrane stability

- A high resolution stencil which enables a variety of patterns without introducing additional processes has not yet been reported

Corrugation membrane

- Increased membrane stability
- High resolution
- Additional fabrication

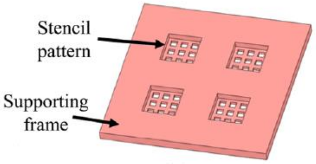


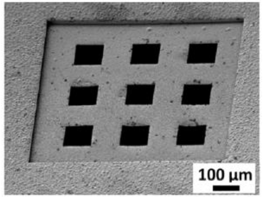


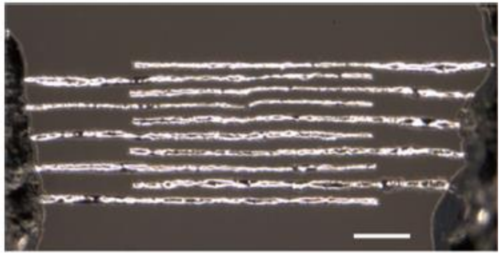
M. A.F. van den Boogaart et al., *Sens. and Act. A, 2006*

Increased membrane thickness (with electroplated Cu)

- Increased membrane stability
- Limited pattern resolution

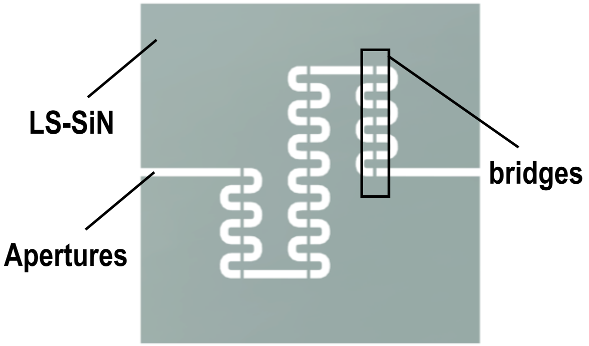






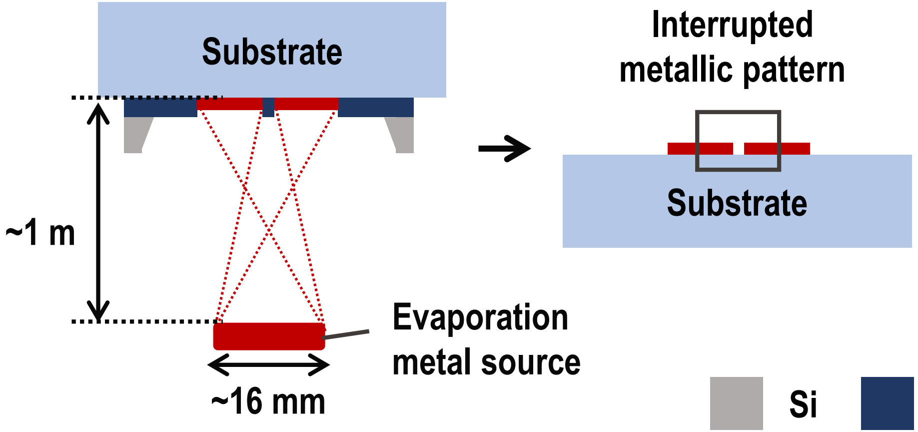
N. Lazarus et al., *Appl. Mater. Interfaces*, 2017

Bridge stencil – operation principle

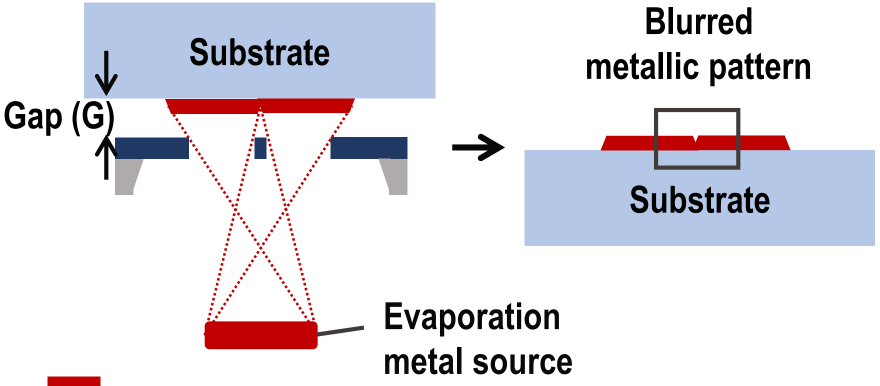


- Sub-micrometer scale patterning
- Resist-less processing
- No additional and costly processes
- Reusability of stencils after a proper etching/cleaning procedure

Stencil placed in contact with the substrate



Stencil lifted a certain distance from the substrate

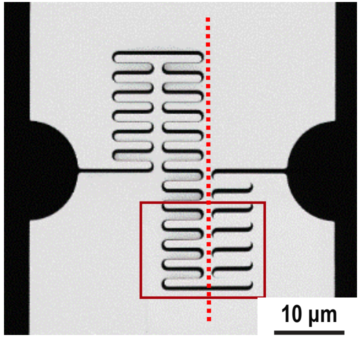


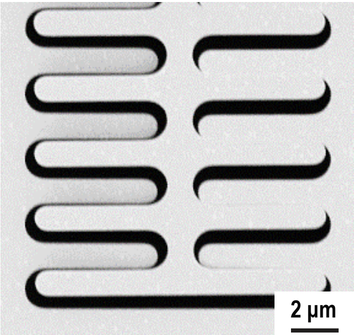
Si SiN Cr/Au

Bridge stencil – comparison

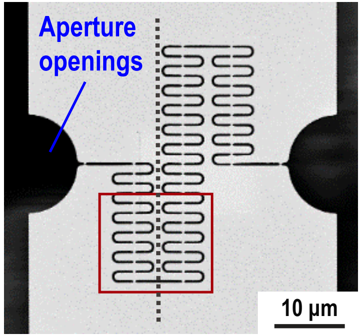
Stencil images
- Apertures: 350 nm, bridges: 250 nm

Without bridges

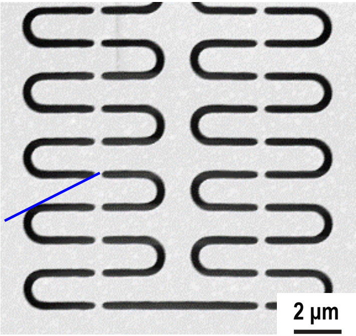




With bridges

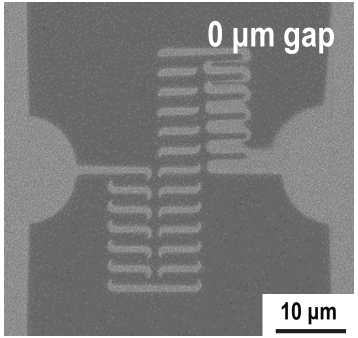


Nano-bridges

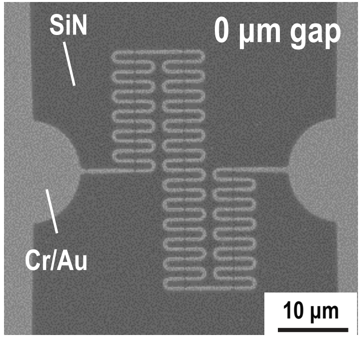


Metal deposition on SiN
- Cr (5 nm)/ Au (50 nm)

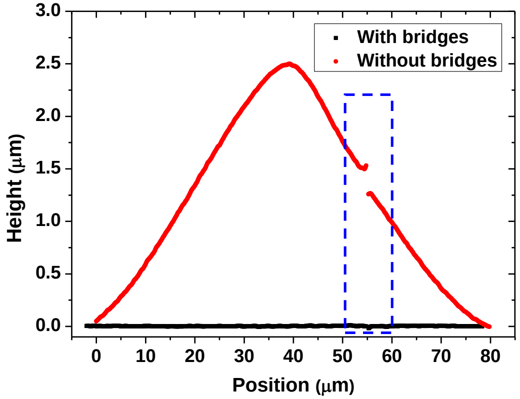
Without bridges

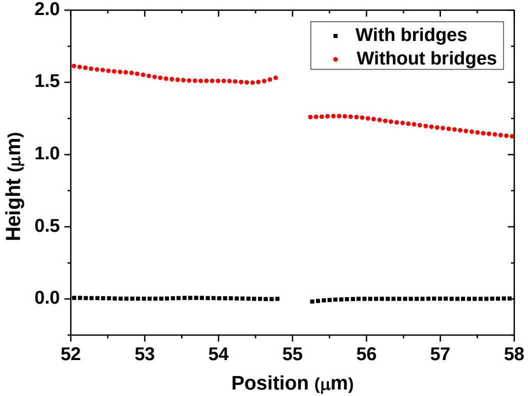


With bridges



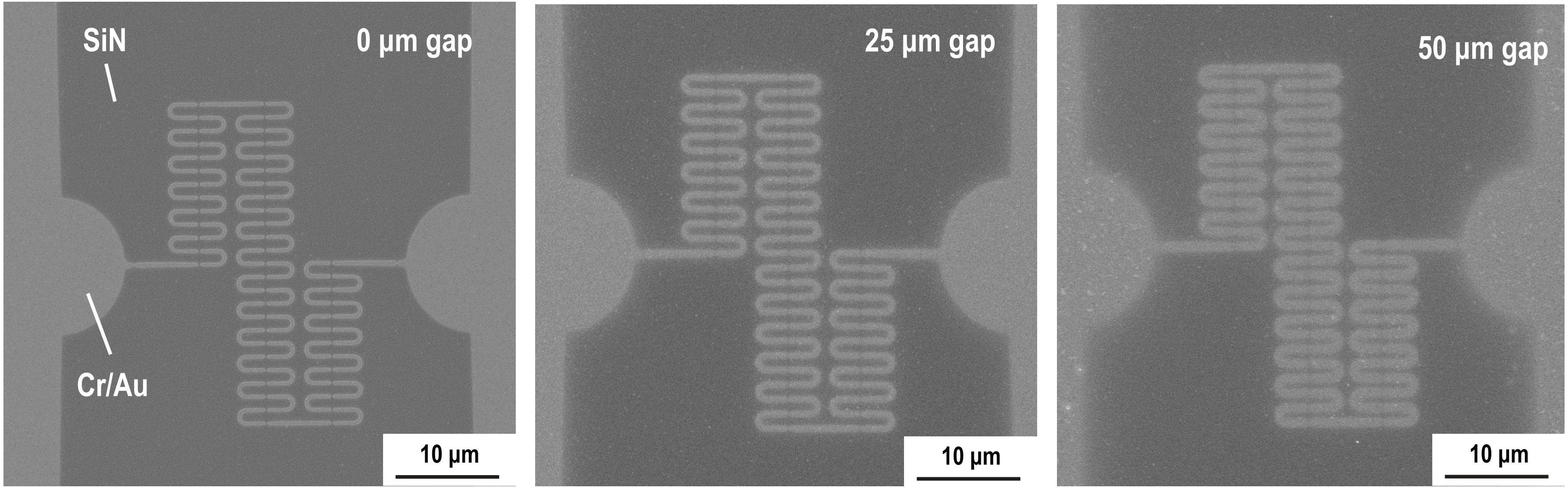
Stencil distortion
- Less than 1 µm bending with bridges





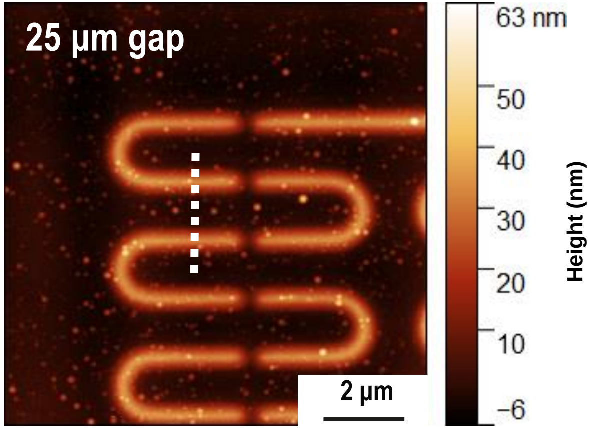
Geometrical characterization

- The widths of the deposited metal are 700 nm and 1000 nm for a gap distance of 25 and 50 µm, respectively

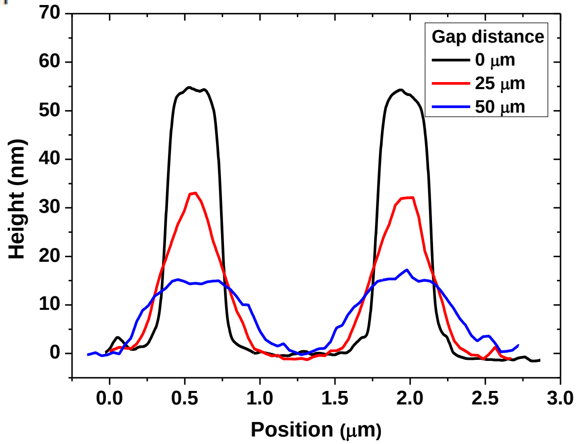


Geometrical characterization

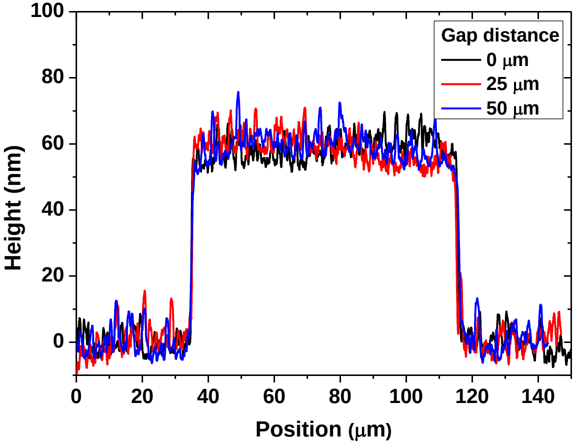
- Observe a thickness reduction of the deposited metals not only under the bridges, but also in the regions under the aperture openings (e.g. 15 nm instead of 55 nm for a gap distance of 50 µm)
- There is no thickness reduction observed for large openings (e.g. an electrical pad having a width of 80 µm)



Nano-slits (0.35 µm openings)



Large apertures (80 µm openings)



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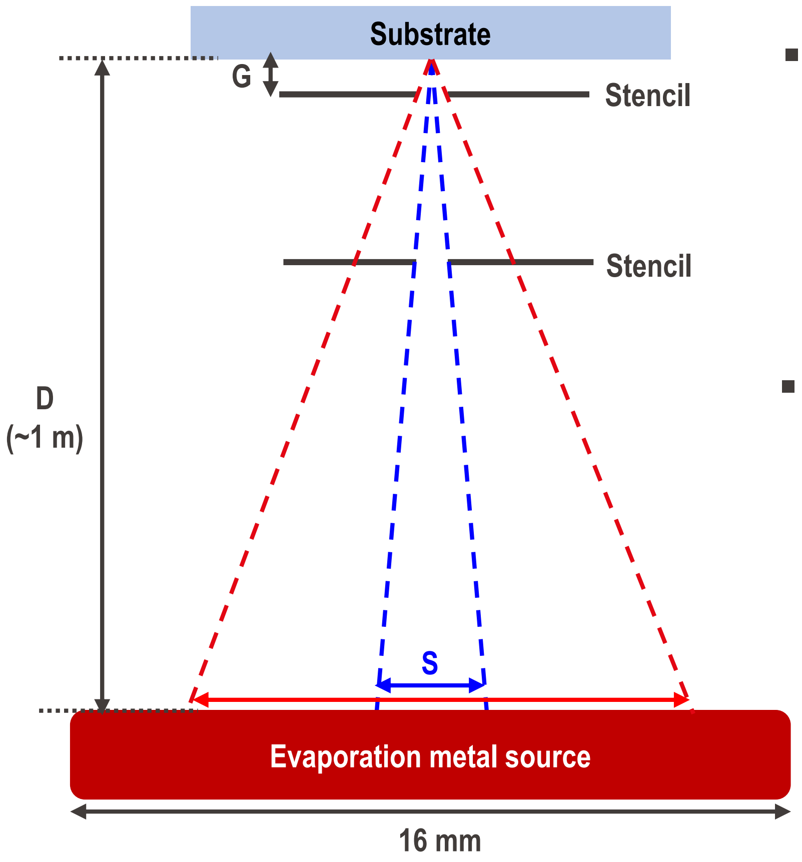
Thickness reduction

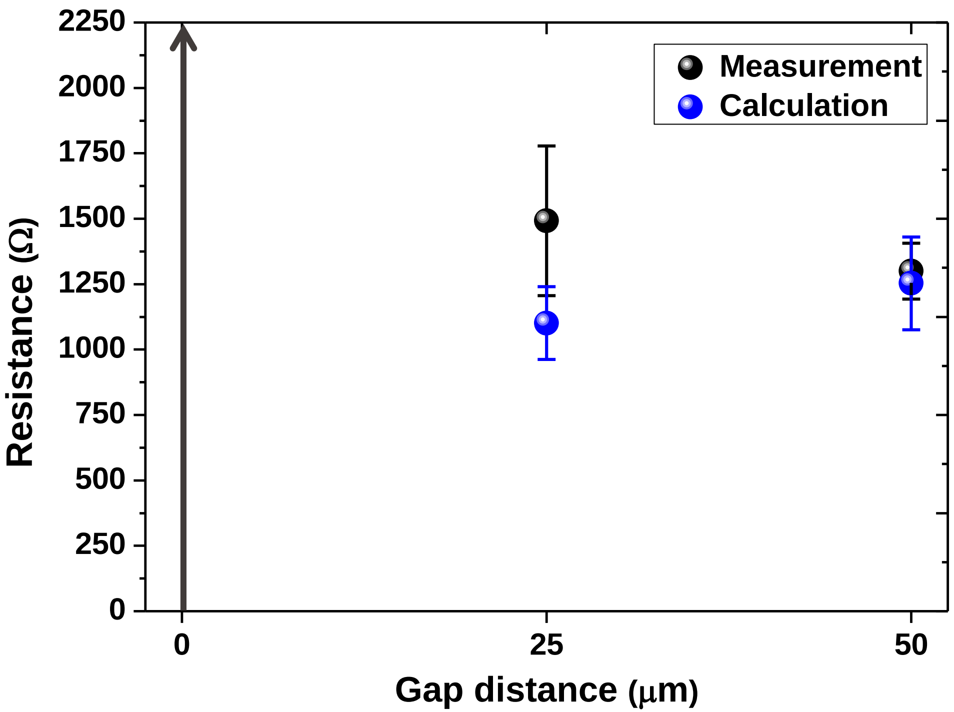


- Parameters:
  - Source diameter: 16 mm
  - D: 1 m
  - G: 50 µm
  - Aperture openings: 0.35 µm / 80 µm

- Preliminary estimation based on the equation, $S = \frac{A \times D}{G}$
  - Small aperture slits: 0.35 µm
    → **80%** of thickness reduction (experimental: **70%**)
  - Large aperture openings (pads): 80 µm
    → **0%** of thickness reduction

Electrical characterization

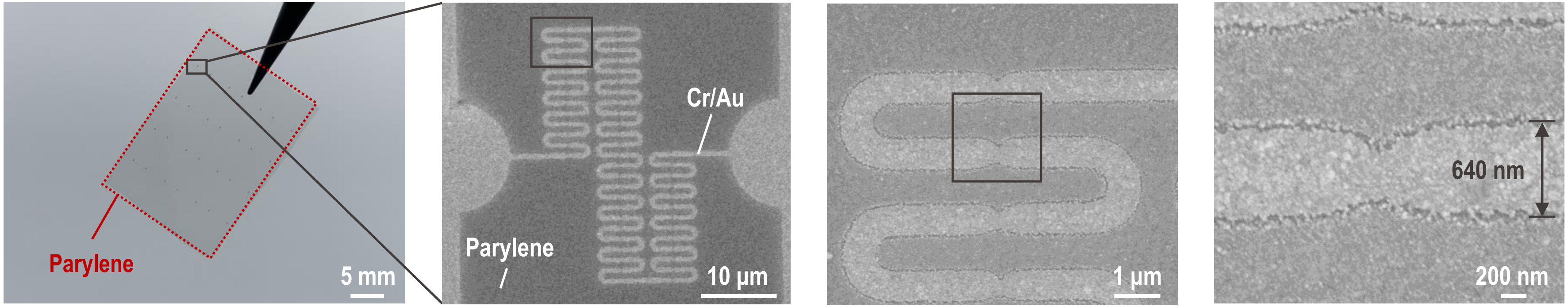
- Infinite resistance for a metal pattern by using the stencil placed in contact with the substrate
- The measured resistance values for both 25 and 50 µm gaps are within 20% deviation from the calculated values



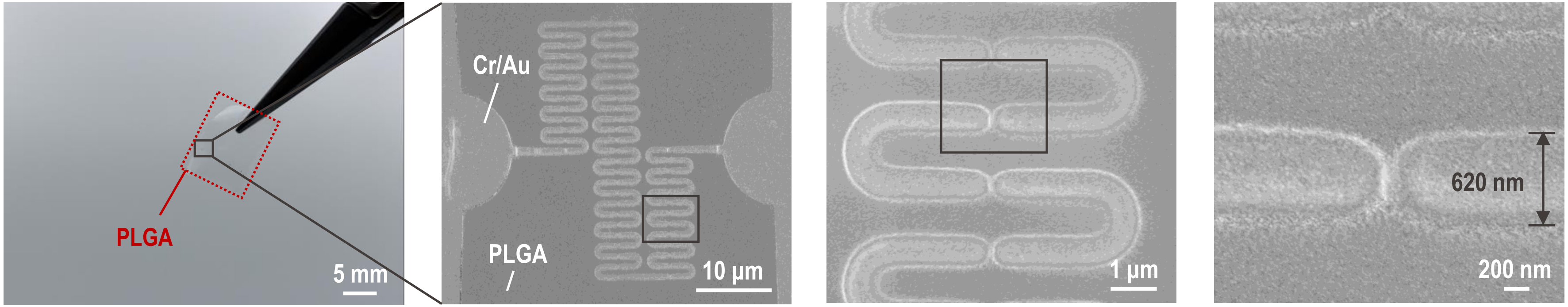
Demonstration on polymeric materials

- Metal patterns are successfully fabricated on polymeric materials with **a gap distance of 25 µm**
- Measured resistances are ~1700 Ω and ~2600 Ω for patterns on Parylene and PLGA substrate, respectively

Biocompatibe Parylene substrate



Biodegradable PLGA substrate



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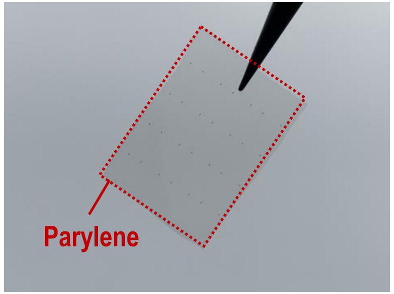
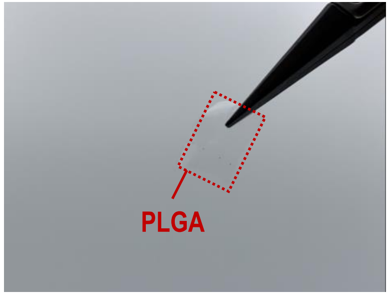
Conclusion and outlook

- Nano-bridges stabilize fragile SiN stencils and enable the creation of long meander-like metallic patterns at sub-micrometer scale

- The observed thickness reduction due to the blocking of the coming evaporant is in agreement with calculation results (80% vs. 70%)

- The demonstrations on biocompatible Parylene and biodegradable PLGA substrates show potential for high-resolution wearable or transient devices
  - The detailed study on the deposited metal morphologies on polymeric substrates
  - Developing functional wearable devices based on the presented work





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