# Additive Manufacturing for the Rapid Prototyping of Economical Biosensors

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## Overview

- As the demand of biological sensors continues to increase, it is important to develop a material that mitigates the ecological footprint, while enhancing the device performance; a promising candidate of which is MXenes with tunable surface functional group, band gap, and mechanical properties.
- Additive electronics manufacturing is a promising technique for the scalable fabrication of various sensors such as optical, gas, force, humidity, and electrochemical sensors. [1]

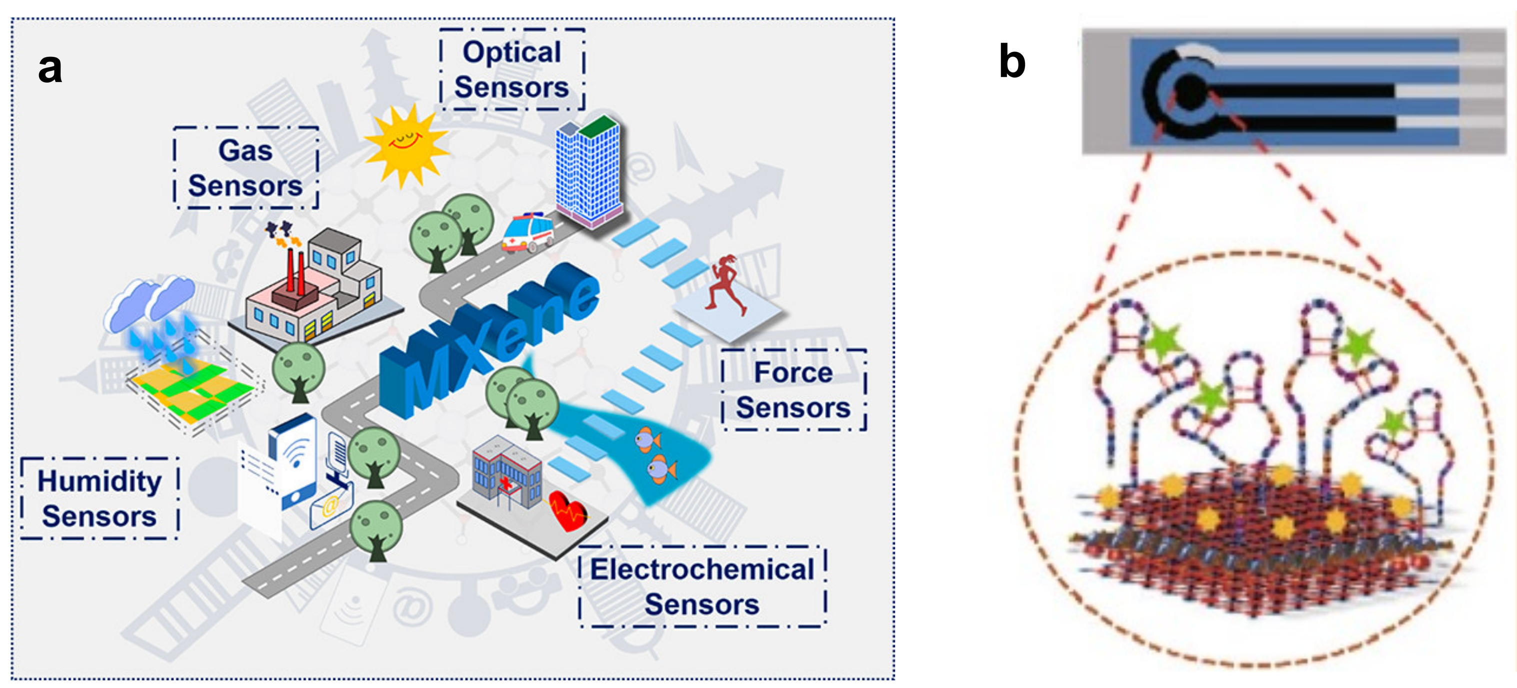


**Fig. 1 (a)**Schematic diagram of MXene sensors [1]. **(b)** MXene biosensor **for** detection through electrochemical method [2].

## MXene Synthesis

✓ **Precursors:** $Ti_3AlC_2$ MAX phases
✓ **Etching:** Required to break strong metallic or covalent bonds, unlike in VdW solids. The aluminum layers are etched using the in situ production of HF through the MILD etching method.
✓ **Delamination:** Produces colloidal solutions of single- or few-layer MXene flakes in water or polar organic solvents.

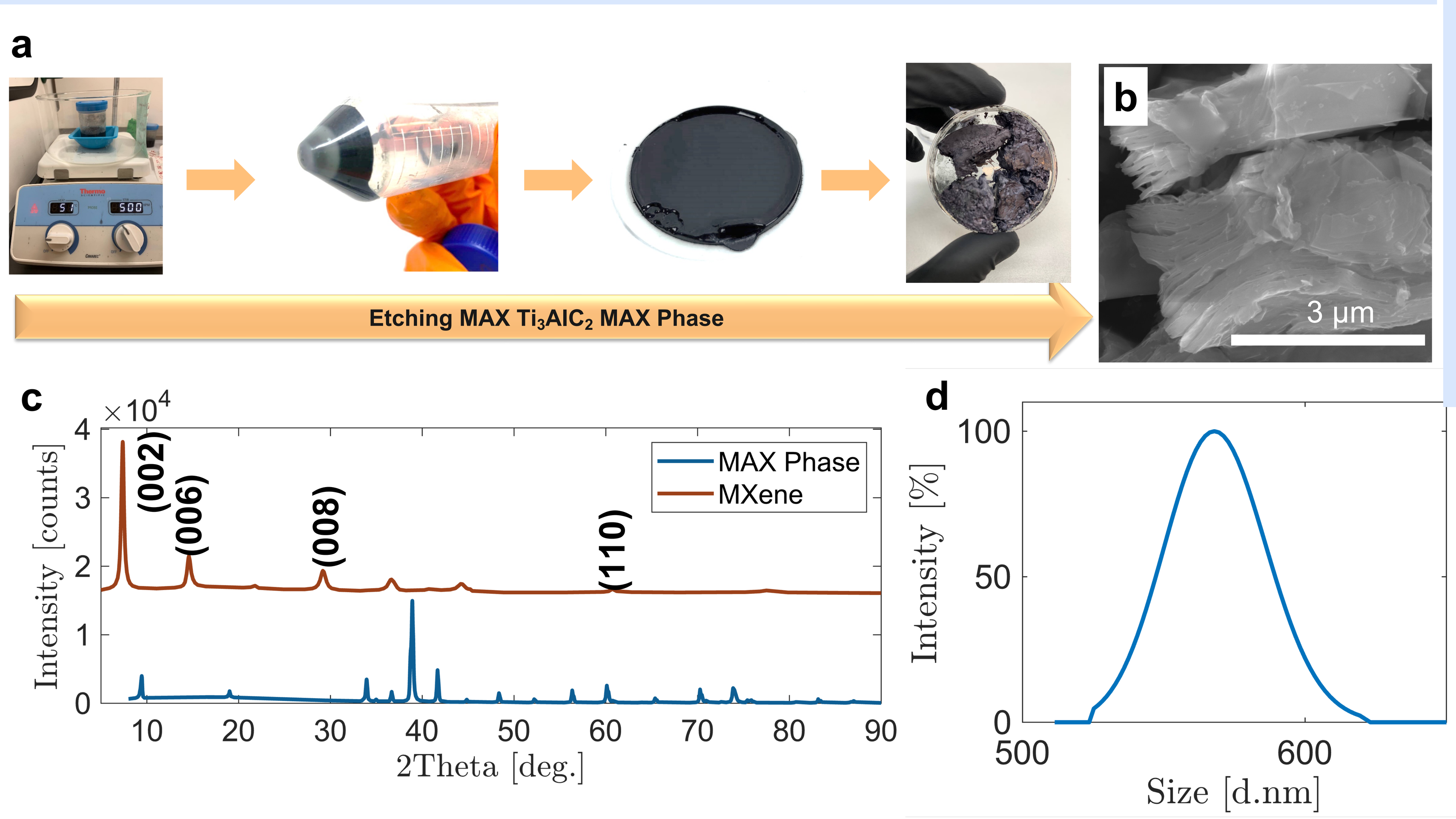


**Fig. 2 (a)** Photograph of synthesis of multi-layer $Ti_3C_2T_x$ MXene from $Ti_3AlC_2$ (MAX phase) , **(b)** Scanning electron microscopy (SEM) image of multilayered $Ti_3C_2T_x$ after etching reaction, **(c)** X-ray diffraction pattern (XRD) of multi-layer $Ti_3C_2T_x$ and $Ti_3AlC_2$ (MAX phase). There is no peak around 40 degree for $Ti_3C_2$ , indicating the removal of aluminum layer from MAX phase, **(d)** Dynamic light scattering (DLS) of exfoliated m-layer $Ti_3C_2T_x$ . The size of particles is less than 1 µm which is compatible with aerosol jet printing technology.

[1]. *ACS Nano* **2021** *15* (3), 3996-4017
[2]. Nano-Micro Lett. **(2022)** 14:100

## Characterization and Ink Formulation

- Size reduction and exfoliation of multi-layered $Ti_3C_2T_x$ to few/mono layer $Ti_3C_2T_x$ is preformed by probe-sonicator.
- The resultant NPs are formulated to an ink compatible with AJP technique.
- The rheology parameters such as viscosity, surface tension, contact angle, and density need to be studied before printing.

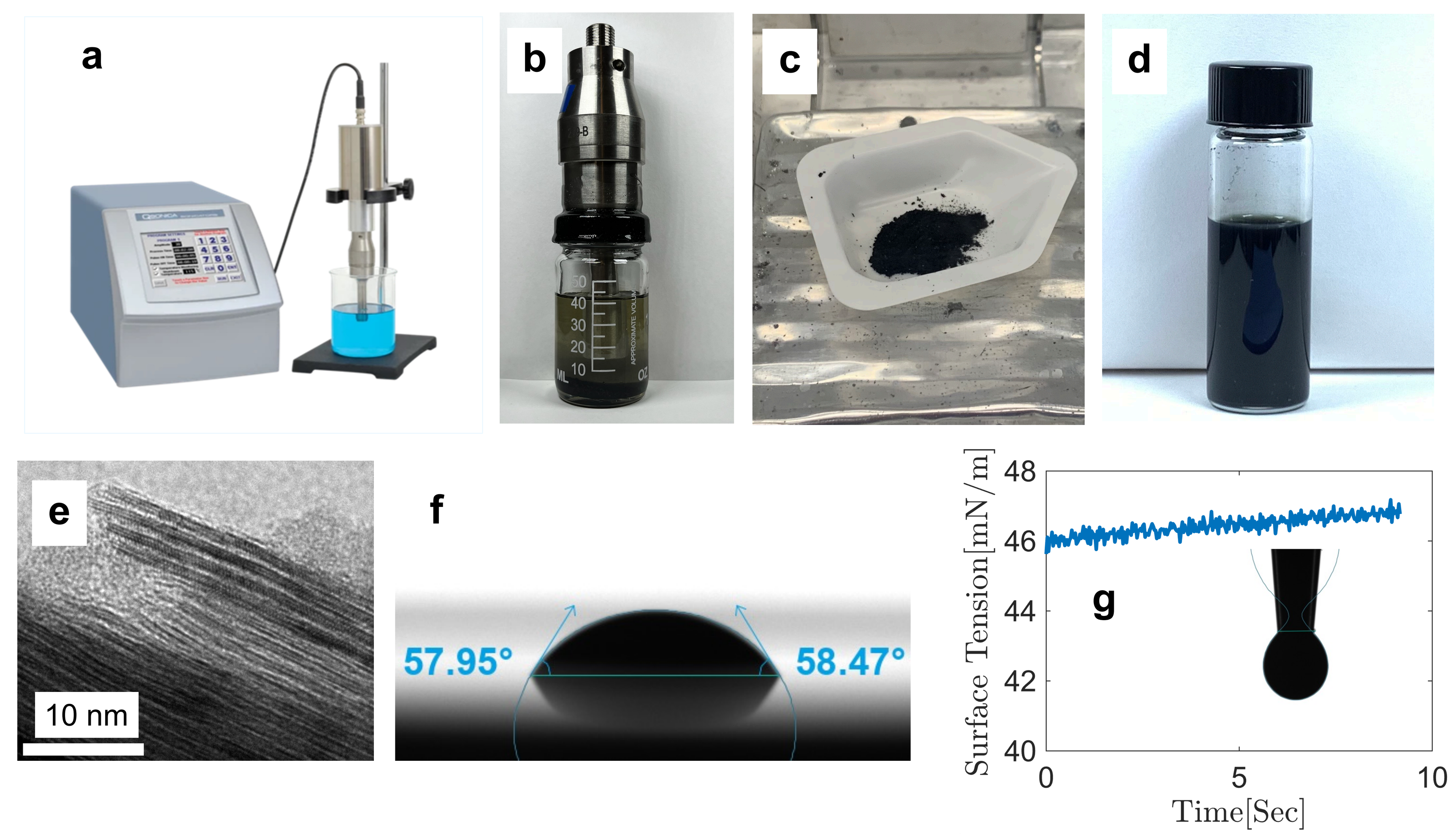


**Fig. 3 (a)** 700QSonica probe sonicator used for exfoliation and size reduction of multi-layer $Ti_3C_2T_x$ MXene **, (b)** Dispersion of multi-layer $Ti_3C_2T_x$ MXene in organic-based solvent in prepared exfoliation setup to avoid oxidization, **(c)** Exfoliated $Ti_3C_2T_x$ MXene after washing step and drying step. **(d)** Formulated ink for AJP technique. **(e)** TEM image of exfoliated $Ti_3C_2T_x$ MXene **(f)** Contact angle measurement of formulated ink on Kapton. **(g)** Surface tension of the formulated ink.

## Aerosol Jet Printing of $Ti_3C_2$

- Aerosol Jet Printing (AJP) is a promising technique for additive electronics manufacturing and is influenced by various variables, including carrier gas flow rate, sheath gas flow rate, nozzle diameter, and atomization frequency.
- This work will enable the manufacturing of biosensors based on $Ti_3C_2$ MXene inks using high-resolution AJP techniques, with specific focus on cortisol based sensors.

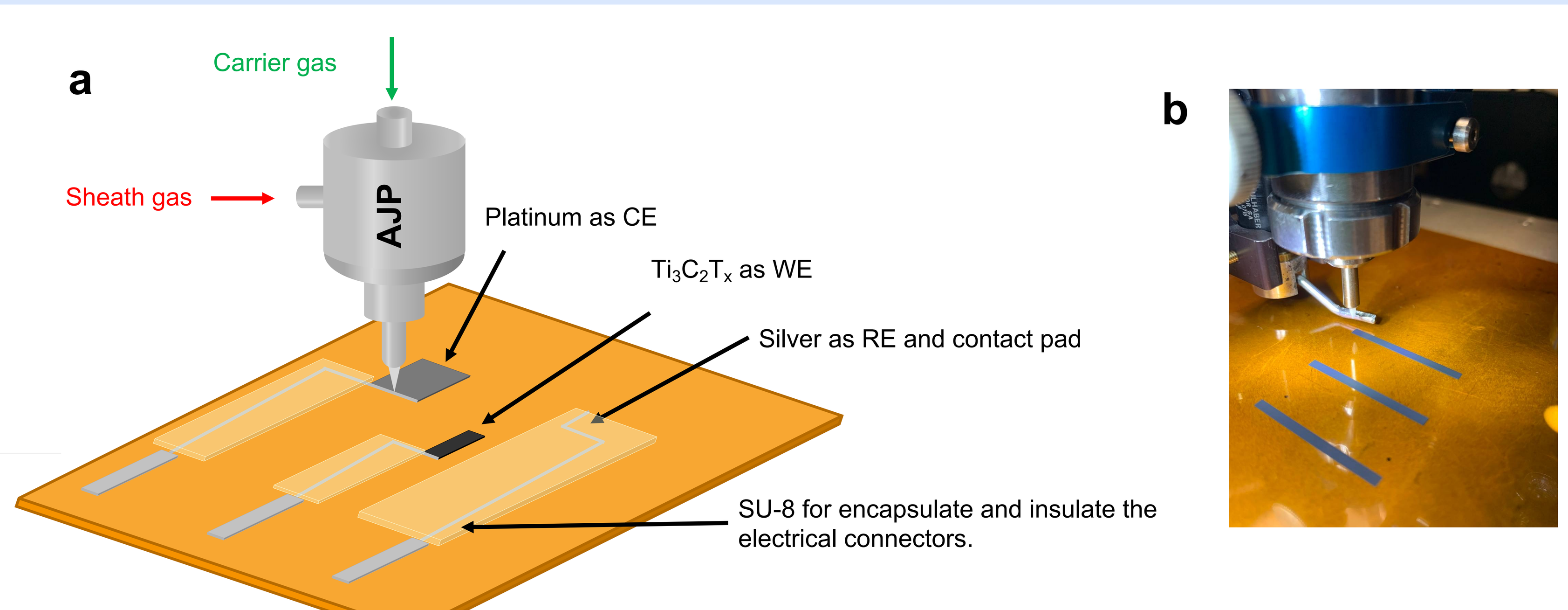


**Fig. 4 (a)** Schematic illustration of electrochemical sensors using $Ti_3C_2T_x$ MXene, platinum, silver, and SU-8 inks on Kapton for biosensors, **(b)** Printing of $Ti_3C_2T_x$ lines on Kapton showing the printability of the formulated $Ti_3C_2T_x$ MXene

## Post-printing Process and Device Geometry

- Post-printing process technique is employed after printing step to achieve bulk-like performance .
- Here we used annealing the printing structure at 300 °C under $Ar/N_2$ gas to remove the solvents from the printed structure.
- The inert condition needs to be preformed to avoid oxidization for printed structure.

The electrochemical sensor will have three electrode design with:
➢ Printed platinum ink as counter electrode.
➢ Printed $Ti_3C_2T_x$ ink as working electrode.
➢ Printed silver ink as reference electrode.
➢ The SU-8 will be used to encapsulate and insulate the electrical connectors.

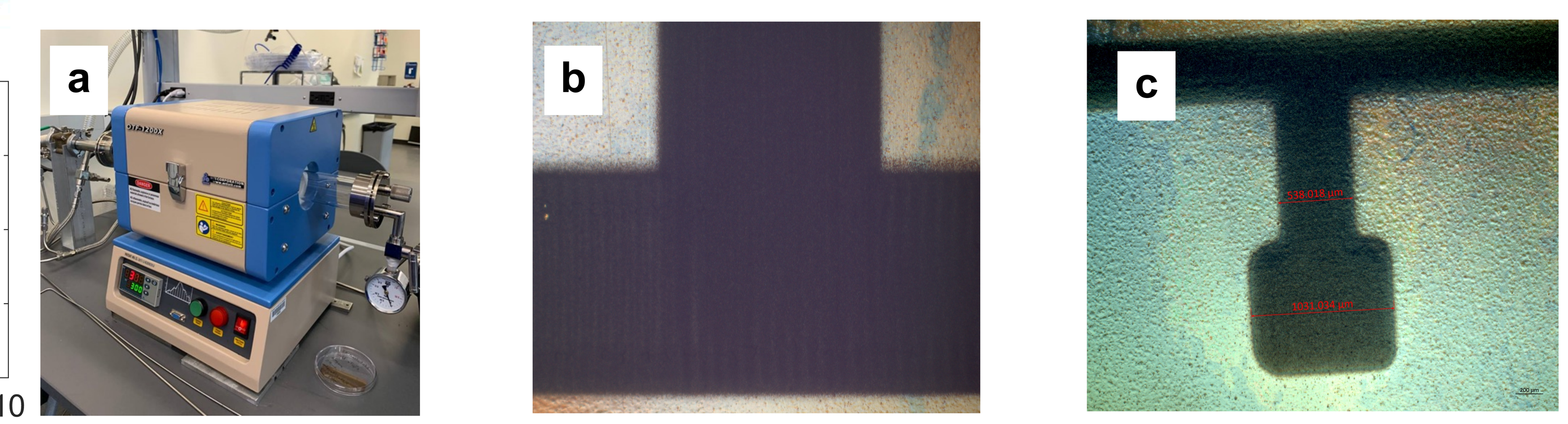


**Fig. 5 (a)** Tube furnace for post-printing process for printed devices. **(b,c)** optical image of some printed $Ti_3C_2T_x$ MXene ink on Kapton after post-printing process showing the formulated ink and printing parameters optimized properly.

## Conclusion/ Future Work

The next steps will be:
- Rheology and contact angle studies of Pt, Ag, and SU-8 ink.
- Printing the Pt, $Ti_3C_2T_x$ , Ag, and SU-8 ink as electrochemical biosensor.
- Surface treatment of printed $Ti_3C_2T_x$.
- Electrochemical performance of printed sensor.

## Acknowledgements

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