MXene Inks for High-Throughput Printing of Electronics

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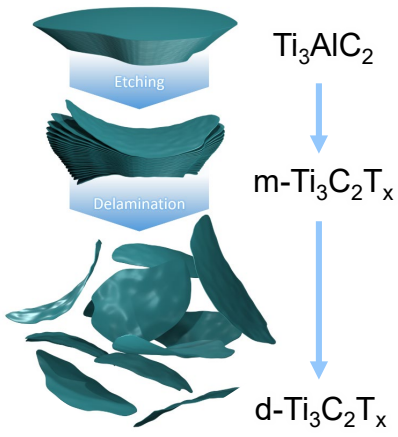
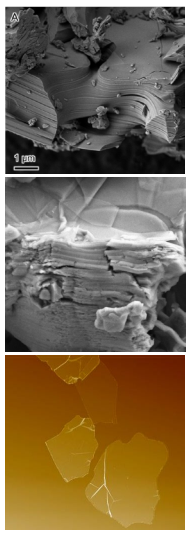
MXene Exfoliation



T_x= surface termination groups

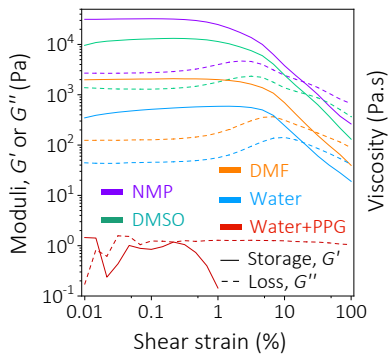


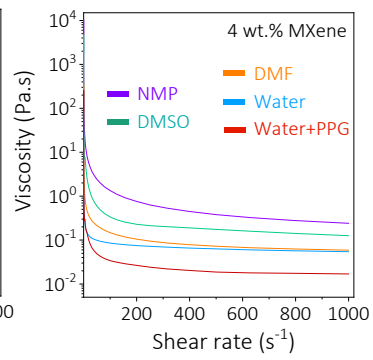
MXenes can be obtained by etching the "Al" layer of the MAX phase (Ti_3AlC_2). The received multi-layer MXene (m-$Ti_3C_2T_x$) can be further processed and exfoliated into single layer and few-layer MXene sheets (d-$Ti_3C_2T_x$).
The delaminated MXene nano sheets, as well as the few layer MXene suspensions can be used to formulate inks for different printing and coating techniques e.g. Gravure- or Screen printing. [1, 2]

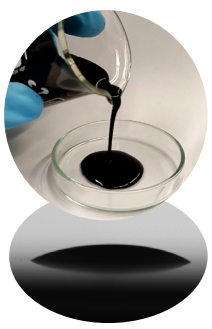
MXene Ink Formulation

The delaminated MXene nano sheets can be dispersed in polar solvents like NMP, DMSO and water (= "good" solvents for MXenes). But already at moderate concentrations (e.g. 4 wt%) the dispersions show high viscosities and tend to form a gel, due to strong interactions. In "bad" solvents like PPG or EG, the dispersion is not stable and the Mxenes aggregate and sediment.
A co-solvent approach (combination of a "good" (minor component) and a "bad" (main component) solvent) can enable a high concentration at low viscosities and thus, a printable ink. The "good solvent" acts as a dispersing agent and helps to disperse MXenes in a printing friendly, organic, "bad" solvent.

→ **Good solvent → high η**
→ **Bad solvents → sedimentation**
→ **It is impossible to formulate a high concentrated ink due to gelation**
→ **Co-solvent approach allows for inks w/ low η @high solid content**
→ **Water acts as dispersing agent**

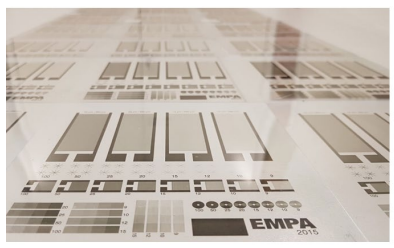


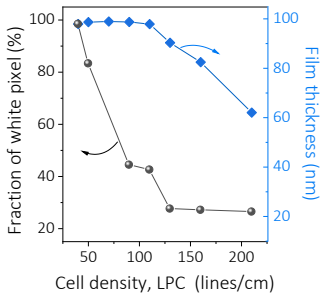




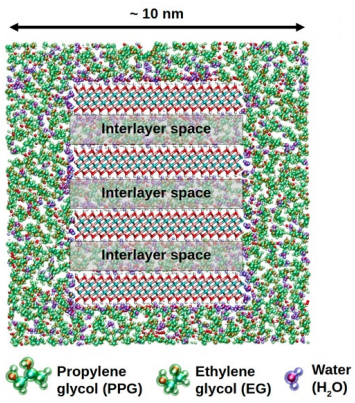
Gravure Printing of MXene Inks

Optimized MXene ink formulation is suitable to be used in a Gravure printing process. Transparent, conductive films (large homogeneous areas) and small features down to ≈ 100 µm width, along with little film thickness (<100 nm) were printed at Empa's CCC.

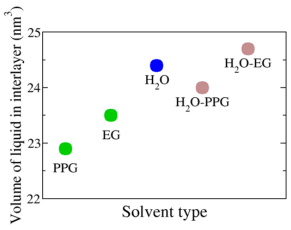




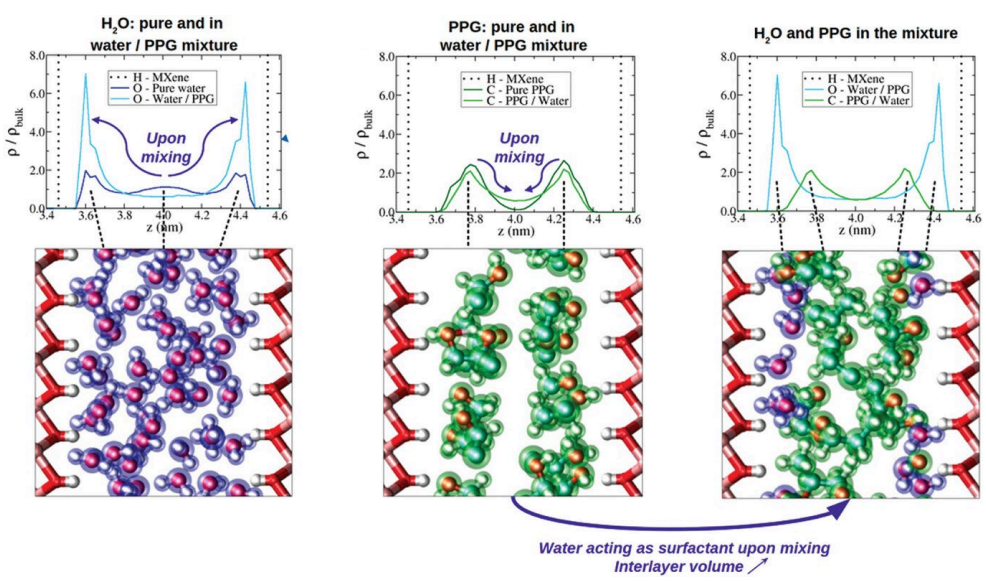
Molecular Dynamics Simulations



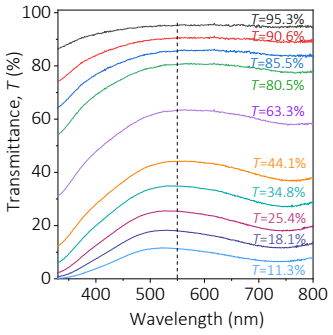
The ability of the solvents to disperse the MXenes was evaluated through the volume of solvent present in the interlayer space. A larger volume will tend to increase the distance between layers and ultimately disperse the MXene material.

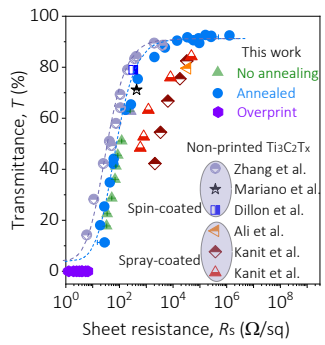


It appears that the strong interactions between water molecules and the charged surface functional groups of the MXene results in the formation of a water-rich layer on the surface of the nanosheets, acting as a dispersing agent for suspending MXenes in water-miscible organic solvents (but still "bad" solvents for MXenes).

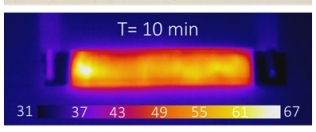


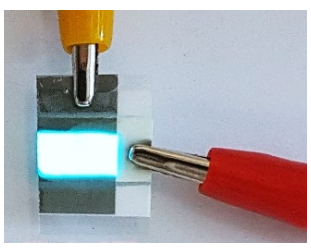
Transparent & Conductive Film



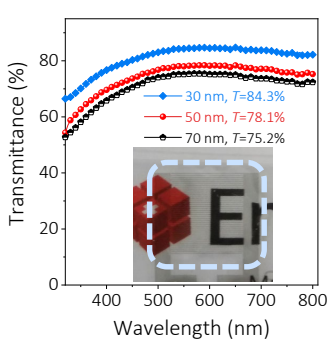


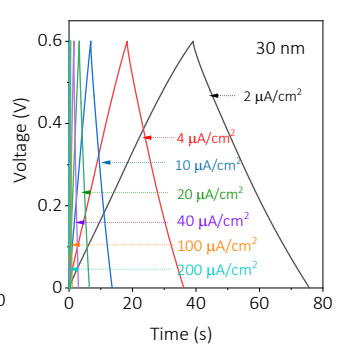
Gravure printed transparent & conductive films show low sheet resistance and high transparency. Films can be used as ITO replacement e.g. as Joule heater or in an Electroluminescent lamp.

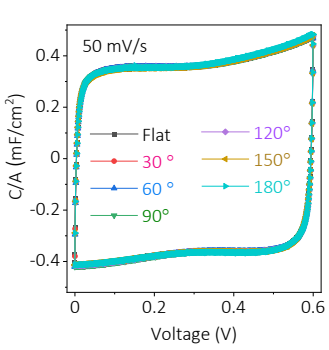




Transparent Energy Storage (Supercap)







Gravure printed interdigitated finger electrodes (made from Mxene) were used to prepare transparent and flexible supercapacitors (with H_2SO_4/PVA electrolyte) for transparent supercapacitor energy storage.

References

[1] Adv. Mater. 2020, 2000716.
[2] Adv.Mater. 2022, 34, 2103660
[3] Adv. Electron. Mater. 2024, 2400170

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