Supplementary Information

Development of Two-Dimensional MXene nanosheets-Based Electrodes via Screen Printing for Low-Frequency Antenna Applications

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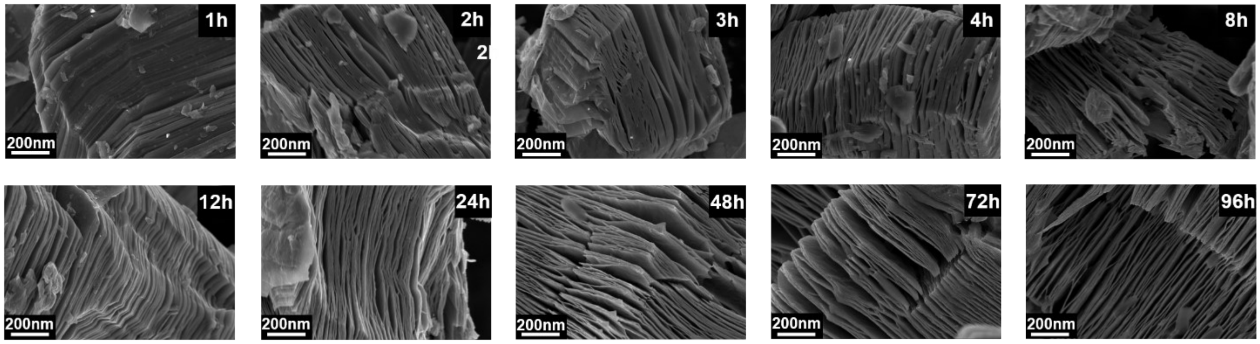

Figure S1. SEM images of Ti_3AlC_2 samples etched for different durations (1 h to 96 h), illustrating the progressive delamination and morphological evolution from the MAX phase to MXene nanosheets.

A series of SEM images was acquired to observe the morphological evolution of the etched samples as a function of etching time. At early time points (1–4 hours), the samples largely retained the dense and compact morphology characteristic of the unetched MAX phase. From 12 hours onward, partial expansion of the layered structure became evident, and more pronounced delamination was observed with increasing duration. Notably, the sample etched for 96 hours (4 days) exhibited the most uniform and fully exfoliated morphology, featuring well-separated and thin lamellar layers. This result indicates that prolonged etching effectively removed the Al atomic layers, thereby facilitating complete conversion to MXene and enabling sufficient interlayer spacing for efficient exfoliation.

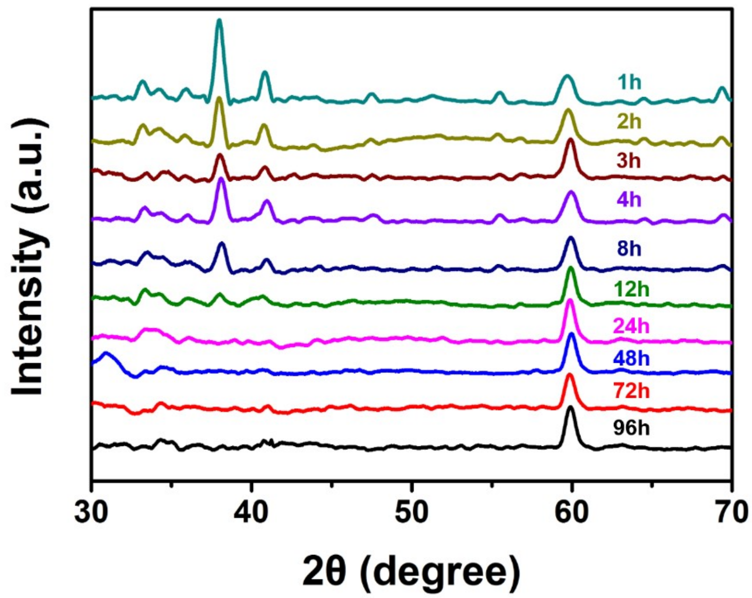

Figure S2. XRD patterns of Ti_3AlC_2 samples etched for varying durations, showing the gradual disappearance of MAX phase peaks and the corresponding formation of MXene, highlighting the effect of etching time on phase conversion.

XRD analysis was conducted to further monitor the structural evolution of Ti_3AlC_2 during the etching process. The diffraction patterns show a gradual decrease in the intensity of the characteristic MAX phase peaks, such as (104) and (105) near 39° and 41°, with increasing etching time. These peaks nearly disappeared after 96 hours, indicating substantial removal of Al and transformation into the MXene phase. In addition, the diffraction peak near 60°, corresponding to in-plane atomic ordering, became noticeably sharper with longer etching durations. This sharpening is attributed to subtle reordering and enhanced in-plane crystallinity induced by structural relaxation following Al removal. While some degree of disorder may be introduced along the out-of-plane direction during exfoliation, the improved in-plane order supports both the structural integrity and the functional performance of the resulting MXene nanosheets.

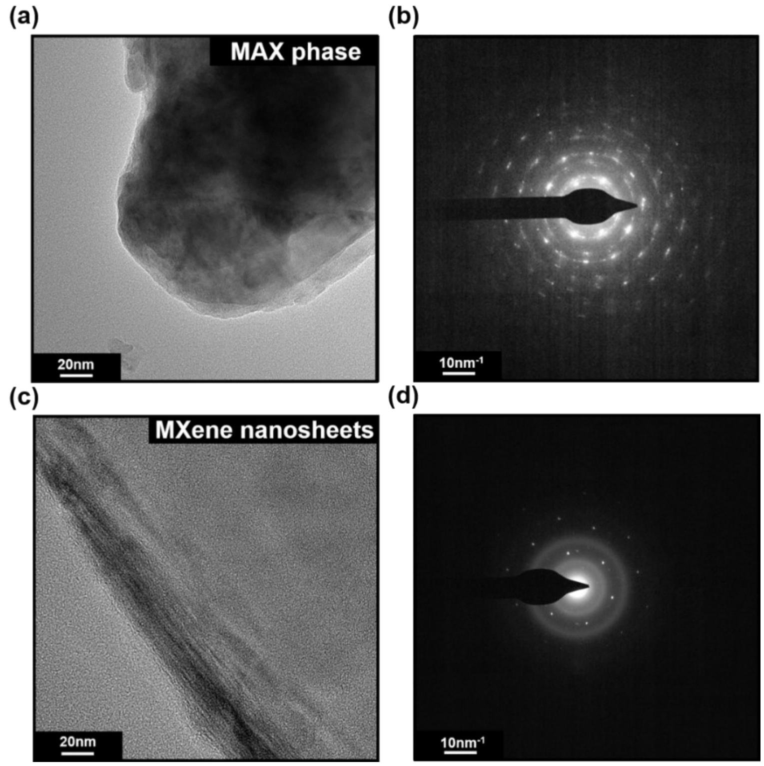

Figure S3. (a) TEM image and (b) corresponding SAED pattern of the MAX phase, (c) TEM image and (d) SAED pattern of MXene nanosheets.

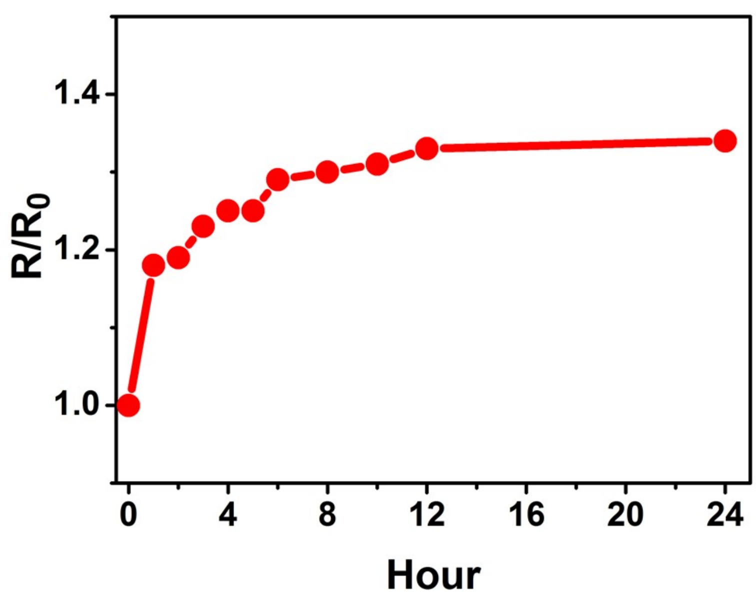

Figure S4. Normalized resistance (R/R_0) of the MXene/PVDF electrode (7:1 weight ratio) during thermal aging at 80 °C over a 24-hour period.