

Validation of MXene Synthesis

The successful etching and exfoliation of the MAX phase into single- to few-layer MXene sheets were confirmed through multiple characterization techniques. Scanning electron microscopy (SEM) images (Figure S1a and S1b) revealed the resulting MXene sheets with varying sizes. X-ray diffraction (XRD) analysis provided further evidence: the disappearance of the MAX phase (104) diffraction peak, which corresponds to the aluminum layer, confirmed its effective removal (Figure S1c). Furthermore, the prominent (002) diffraction peak shifted from $\sim 9.5^\circ$ reduced to 7.0° , which is consistent with MXene. As quantified by Bragg's law, this shift corresponds to an increase in the interplanar distance from 0.92 nm to 1.26 nm, confirming the exfoliation of the layers and the introduction of surface functional groups.

The morphology of individual sheets was analyzed using atomic force microscopy (AFM). Samples were prepared by drop-casting a MXene solution onto silicon wafers, and images were acquired using Bruker MultiMode 8-HR instrument in ScanAsyst mode to measure sheet thickness. For XRD analysis of films, samples were mounted on a zero background SiO_2 substrate. Patterns were recorded on a PANalytical X'Pert Powder diffractometer using $\text{Cu K}\alpha$ radiation ($\lambda = 1.54 \text{ \AA}$) with a 2θ scan step of 0.013° and 100 ms dwell time.

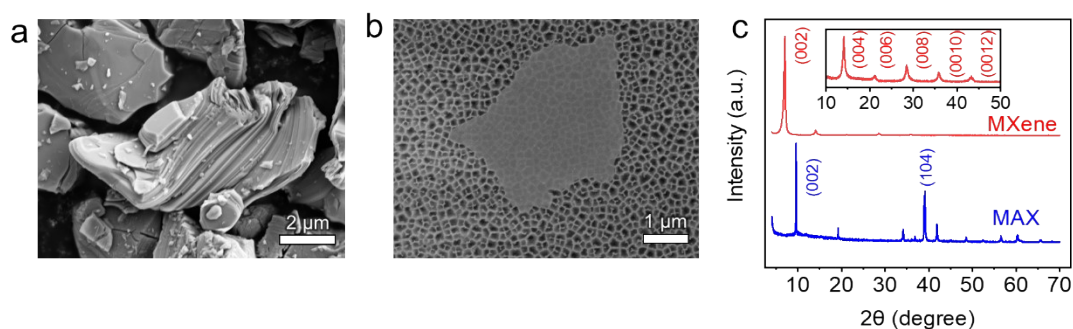


Figure S1. Validation of $\text{Ti}_3\text{C}_2\text{T}_x$ MXene synthesis. SEM images of (a) the Ti_3AlC_2 MAX phase precursor and (b) the resulting $\text{Ti}_3\text{C}_2\text{T}_x$ MXene sheets produced *via* the MILD method. (c) XRD patterns of the MAX phases and MXene. The disappearance of the MAX (104)

diffraction confirms the successful etching of the aluminum layer, while the downshifting of the (002) peaks indicate successful delamination and an increase in the c-lattice parameter.

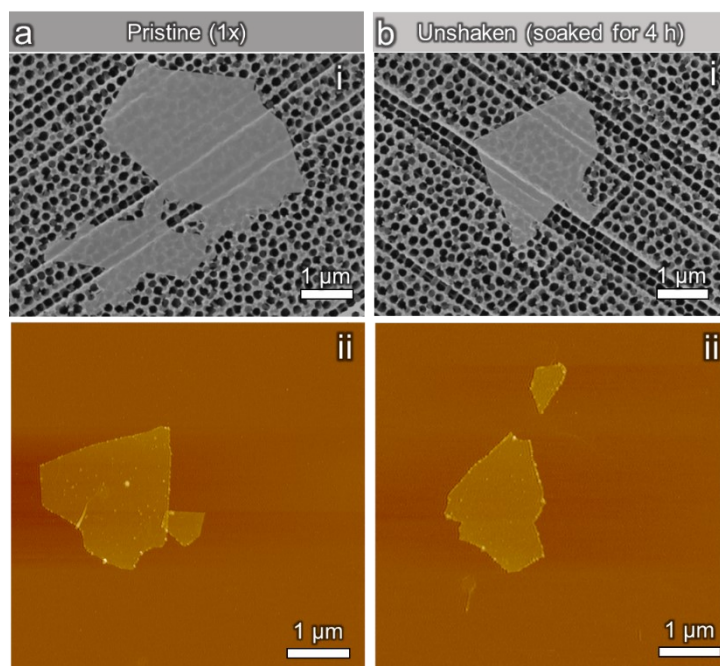


Figure S2. Scanning electron microscopy images (i) and atomic force microscopy profiles (ii) of (a) pristine $\text{Ti}_3\text{C}_2\text{T}_x$ MXene flakes and (b) corresponding samples left undisturbed for an additional 4 hours, matching the duration of the full solvent exchange procedure.

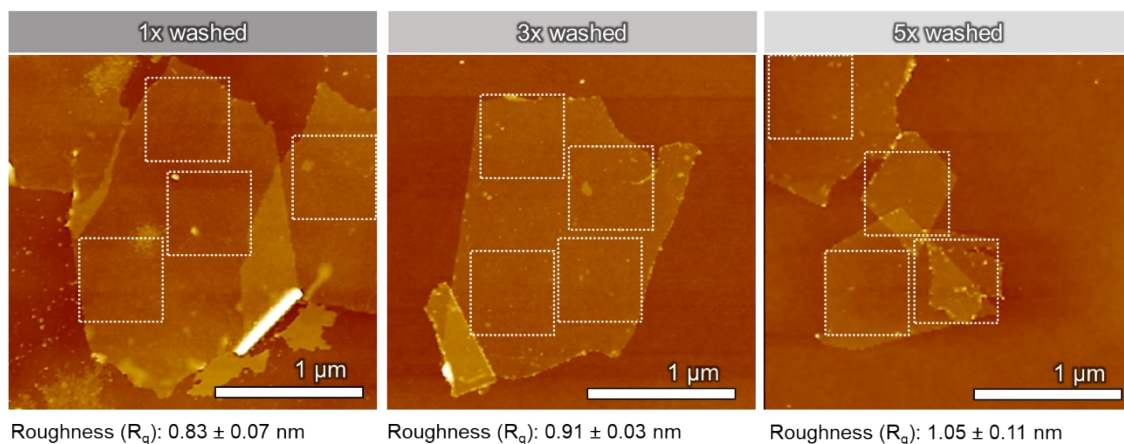


Figure S3. AFM roughness profiles of the 1x, 3x, and 5x washed samples indicate an increase in surface roughness, consistent with the development of oxide grains

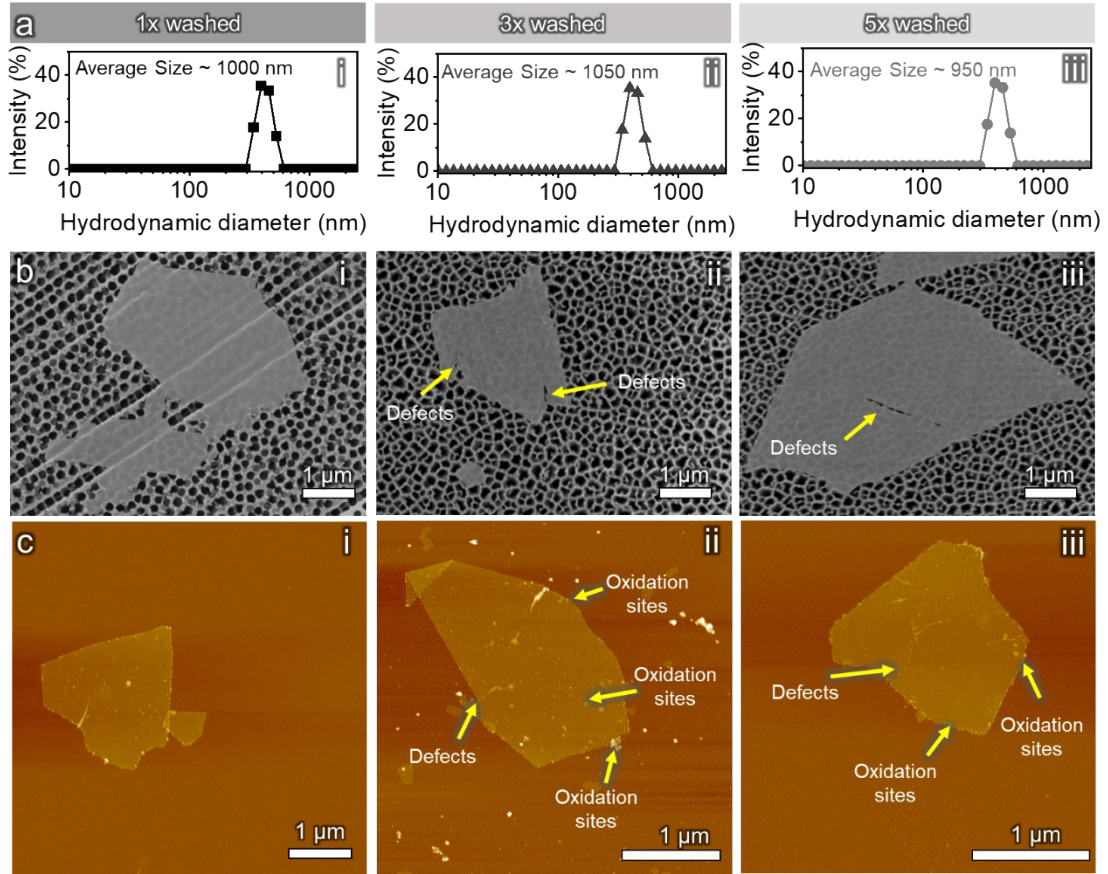


Figure S4. Effect of successive washing cycles on $\text{Ti}_3\text{C}_2\text{T}_x$ MXene sheets. (a) Dynamic light scattering size distributions, (b) scanning electron microscopy images, and (c) atomic force microscopy profiles of $\text{Ti}_3\text{C}_2\text{T}_x$ MXene sheets after 1x, 3x, and 5x washing cycles.

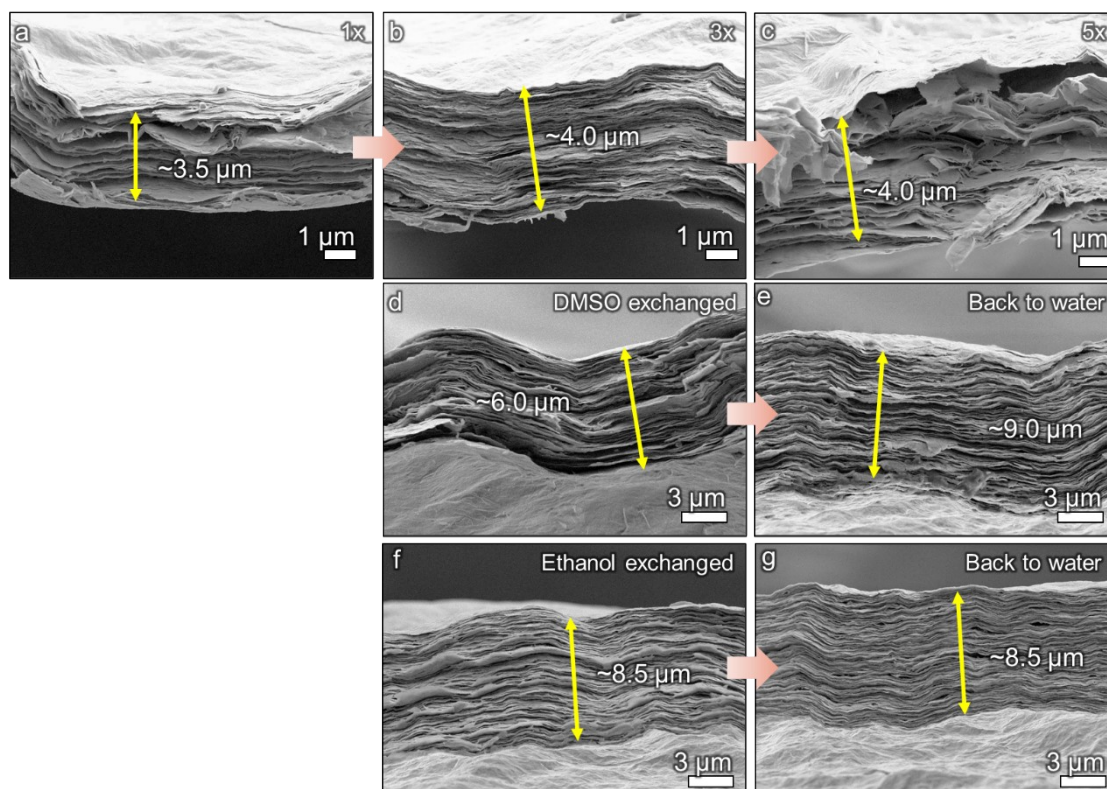


Figure S5. Cross-sectional scanning electron microscopy images of the MXene films. The thickness measured from these images was used to normalize the data measured *via* 4-probe method to obtain the values of electrical conductivity.

Table S1. Percent Peak Area of Ti 2p, O 1s and C 1s core spectra for 1x samples.

1x								
	Bonds	Estimated Position	Trial			Peak area		
			1	2	3	Ave	StDev	STError
Titanium	TiC 3/2	454.8	9.51	9.23	7.7	8.813333	0.974286	0.562504
	TiC 1/2	460.5	3.33	2.54	2.31	2.726667	0.535008	0.308887
	Ti (IV) 3/2	458.7	4.43	5.86	4.65	4.98	0.77	0.44456
	Ti (IV) 1/2	464.6	0.66	0.59	0.93	0.726667	0.179536	0.103655
	Ti (II) 3/2	455.5	17.02	30.63	19.07	22.24	7.337895	4.236536
	Ti (II) 1/2	461.4	6.82	13.03	8.11	9.32	3.277057	1.89201
	Ti (III) 3/2	456.6	40.84	26.57	40.14	35.85	8.044333	4.644398
	Ti (III) 1/2	462.4	17.38	11.38	17.08	15.28	3.380828	1.951922
Oxygen	C-Ti-OH	531.6	48.4	45.55	48.01	47.32	1.545218	0.892132
	O-Ti-O	529.6	41.55	40.83	44.53	42.30333	1.961666	1.132568
	C-Ti-Ox	530.6	10.05	13.63	7.46	10.38	3.098209	1.788752
Carbon	C-Ti	281.8	47.41	45.32	53.91	48.88	4.479699	2.586355
	C-Ti-O	282.3	7.16	9.3	7.71	8.056667	1.111321	0.641621
	C-O	285.1	8.6	9.91	6.65	8.386667	1.640437	0.947107
	C-C	284.1	36.33	35.39	30.83	34.18333	2.941859	1.698483
	O=C-O	288	0.49	0.09	0.9	0.493333	0.40501	0.233833

Table S2. Percent Peak Area of Ti 2p, O 1s and C 1s core spectra for 3x samples.

3x								
	Bonds	Estimated Position	Trial			Peak area		
			1	2	3	Ave	StDev	STError
Titanium	TiC 3/2	454.8	9.72	7.79	7.559	8.356333	1.186605	0.685086
	TiC 1/2	460.5	2.67	1.95	2.09	2.236667	0.38175	0.220404
	Ti (IV) 3/2	458.7	8.45	8.2	7.82	8.156667	0.317228	0.183151
	Ti (IV) 1/2	464.6	0.93	0.9	0.86	0.896667	0.035119	0.020276
	Ti (II) 3/2	455.5	21.28	22.09	21.13	21.5	0.51643	0.298161
	Ti (II) 1/2	461.4	8.52	8.84	8.46	8.606667	0.204287	0.117945
	Ti (III) 3/2	456.6	34.1	35.37	36.65	35.37333	1.275003	0.736123
	Ti (III) 1/2	462.4	14.34	14.87	15.41	14.87333	0.535008	0.308887
Oxygen	C-Ti-OH	531.6	45.01	47.57	46.92	46.5	1.330677	0.768266
	O-Ti-O	529.6	28.33	27.01	27.06	27.46667	0.748086	0.431908
	C-Ti-Ox	530.6	26.65	25.42	26.01	26.02667	0.615169	0.355168
Carbon	C-Ti	281.8	32.34	35.02	33.52	33.62667	1.34318	0.775486
	C-Ti-O	282.3	7.6	8.85	9.62	8.69	1.019461	0.588586
	C-O	285.1	25.96	21.88	22.52	23.45333	2.194296	1.266877
	C-C	284.1	30.47	30.84	31.58	30.96333	0.565184	0.326309
	O=C-O	288	3.63	3.41	2.77	3.27	0.446766	0.257941

Table S3. Percent Peak Area of Ti 2p, O 1s and C 1s core spectra for 5x samples.

5x								
	Bonds	Estimated Position	Trial			Peak area		
			1	2	3	Ave	StDev	STError
Titanium	TiC 3/2	454.8	8.1	9.67	9.29	9.48	0.268701	0.155134
	TiC 1/2	460.5	2.23	2.92	2.56	2.74	0.254558	0.146969
	Ti (IV) 3/2	458.7	13.66	15.54	13.54	14.54	1.414214	0.816497
	Ti (IV) 1/2	464.6	3.08	2.82	3.39	3.105	0.403051	0.232702
	Ti (II) 3/2	455.5	20.19	19.37	14.48	16.925	3.457752	1.996334
	Ti (II) 1/2	461.4	8.08	7.76	5.8	6.78	1.385929	0.800167
	Ti (III) 3/2	456.6	30.27	30.42	35.12	32.77	3.323402	1.918767
	Ti (III) 1/2	462.4	14.39	14.46	15.82	15.14	0.961665	0.555218
Oxygen	C-Ti-OH	531.6	55.89	50.75	49.52	50.135	0.869741	0.502145
	O-Ti-O	529.6	20.8	17.43	19.2	18.315	1.251579	0.722599
	C-Ti-Ox	530.6	23.31	31.82	31.28	31.55	0.381838	0.220454
Carbon	C-Ti	281.8	27.8	29.78	29.04	29.41	0.523259	0.302104
	C-Ti-O	282.3	7.67	7.68	7.7	7.69	0.014142	0.008165
	C-O	285.1	31.22	33.25	30.71	31.98	1.796051	1.036951
	C-C	284.1	26.64	22.25	26.39	24.32	2.927422	1.690148
	O=C-O	288	6.66	7.04	6.16	6.6	0.622254	0.359258

Table S4. Percent Peak Area of Ti 2p, O 1s and C 1s core spectra for DMSO 3x samples.

DMSO 3x								
	Bonds	Estimated Position	Trial			Peak area		
			1	2	3	Ave	StDev	STError
Titanium	TiC 3/2	454.8	12.78	14.26	14.25	13.76333	0.851606	0.491675
	TiC 1/2	460.5	2.52	4.28	3.92	3.573333	0.929803	0.536822
	Ti (IV) 3/2	458.7	5.87	5.72	6.11	5.9	0.196723	0.113578
	Ti (IV) 1/2	464.6	0.59	0.63	0.67	0.63	0.04	0.023094
	Ti (II) 3/2	455.5	14.52	15.99	13.69	14.73333	1.164746	0.672466
	Ti (II) 1/2	461.4	5.81	6.4	5.48	5.896667	0.466083	0.269093
	Ti (III) 3/2	456.6	39.92	36.34	38.52	38.26	1.804106	1.041601
	Ti (III) 1/2	462.4	16.99	16.37	17.35	16.90333	0.495715	0.286201

Table S5. Percent Peak Area of Ti 2p, O 1s and C 1s core spectra for DMSO samples redispersed back into water.

DMSO then back into water								
	Bonds	Estimated Position	Trial			Peak area		
			1	2	3	Ave	St _{dev}	ST _{Error}
Titanium	TiC 3/2	454.8	10.66	11.95	10.09	10.9	0.952943	0.550182
	TiC 1/2	460.5	2.93	3.29	2.78	3	0.262107	0.151327
	Ti (IV) 3/2	458.7	5.81	5.5	5.91	5.74	0.213776	0.123423
	Ti (IV) 1/2	464.6	0.58	0.55	0.59	0.573333	0.020817	0.012019
	Ti (II) 3/2	455.5	17.42	15.7	17.39	16.83667	0.984496	0.568399
	Ti (II) 1/2	461.4	6.54	6.29	6.53	6.453333	0.141539	0.081718
	Ti (III) 3/2	456.6	39.32	39.79	39.77	39.62667	0.265769	0.153442
	Ti (III) 1/2	462.4	16.73	16.93	16.92	16.86	0.112694	0.065064

Table S6. Percent Peak Area of Ti 2p, O 1s and C 1s core spectra for DMSO 3x samples then annealed at 200 °C.

DMSO 3x annealed at 200 °C								
	Bonds	Estimated Position	Trial			Peak area		
			1	2	3	Ave	St _{Dev}	ST _{Error}
Titanium	TiC 3/2	454.8	11.04	11.26	10.7	11	0.282135	0.162891
	TiC 1/2	460.5	3.04	3.1	2.94	3.026667	0.080829	0.046667
	Ti (IV) 3/2	458.7	6.9	7.15	7.35	7.133333	0.225462	0.130171
	Ti (IV) 1/2	464.6	0.69	0.79	0.81	0.763333	0.064291	0.037118
	Ti (II) 3/2	455.5	16.07	18.02	16.11	16.73333	1.114465	0.643437
	Ti (II) 1/2	461.4	6.43	7.21	6.45	6.696667	0.444672	0.256732
	Ti (III) 3/2	456.6	39.17	36.18	39.04	38.13	1.69	0.975722
	Ti (III) 1/2	462.4	16.66	16.3	16.61	16.52333	0.195021	0.112596

Table S7. Percent Peak Area of Ti 2p, O 1s and C 1s core spectra for DMSO samples redispersed back into water then annealed at 200 °C.

DMSO then back into water then annealed at 200 °C								
	Bonds	Estimated Position	Trial			Peak area		
			1	2	3	Ave	St _{Dev}	ST _{Error}
Titanium	TiC 3/2	454.8	8.95	8.23	8.38	8.52	0.379868	0.219317
	TiC 1/2	460.5	2.46	2.26	2.31	2.343333	0.104083	0.060093
	Ti (IV) 3/2	458.7	9.4	10.11	9.99	9.833333	0.380044	0.219418
	Ti (IV) 1/2	464.6	1.03	2.02	2	1.683333	0.565892	0.326718
	Ti (II) 3/2	455.5	21.93	19.62	21.25	20.93333	1.187111	0.685379
	Ti (II) 1/2	461.4	8.78	7.86	8.51	8.383333	0.472899	0.273028
	Ti (III) 3/2	456.6	33.29	34.4	32.24	33.31	1.080139	0.623618
	Ti (III) 1/2	462.4	14.16	15.49	15.33	14.99333	0.726108	0.419219

Table S8. Atomic Compositions of samples dispersed in DMSO and redispersed back into water, both dried at RT and annealed at 200 °C.

DMSO 3x		C	Ti	O	F	S	N
	T1	40.4	24.27	18.45	11.22	3.38	2.27
	T2	37.93	25.43	19.48	11.85	3.14	2.18
	T3	38.22	26.57	20.11	12.07	3.03	0
	Ave	38.85	25.42	19.35	11.71	3.18	1.48
	SD	1.35	1.15	0.84	0.44	0.18	1.29
DMSO 3x - annealed		C	Ti	O	F	S	N
	T1	36.94	28.99	18.82	12.27	1.24	1.73
	T2	36.4	28.85	19.14	12.42	1.35	1.84
	T3	37.12	28.51	18.67	12.06	1.4	2.24
	Ave	36.82	28.78	18.88	12.25	1.33	1.94
	SD	0.37	0.25	0.24	0.18	0.08	0.27
DMSO - water 5x		C	Ti	O	F	S	N
	T1	35.93	30.31	15.78	12.79	3.02	2.17
	T2	34.56	29.9	16.26	14.29	3.15	1.83
	T3	32.75	30.75	17.01	14.27	3.12	2.1
	Ave	34.41	30.32	16.35	13.78	3.10	2.03
	SD	1.60	0.43	0.62	0.86	0.07	0.18
DMSO - water annealed		C	Ti	O	F	S	N
	T1	42.24	24.29	19.97	9.84	0.07	3.59
	T2	41.98	23.49	21.25	9.4	0.08	3.81
	T3	42.64	23.4	20.64	9.24	0.12	3.95
	Ave	42.29	23.73	20.62	9.49	0.09	3.78
	SD	0.33	0.49	0.64	0.31	0.03	0.18

Table S9. Percent Peak Area of Ti 2p, O 1s and C 1s core spectra for ethanol 3x samples.

Ethanol 3x								
	Bonds	Estimated Position	Trial			Peak area		
			1	2	3	Ave	St _{Dev}	ST _{Error}
Titanium	TiC 3/2	454.8	9.68	10.99	7.17	9.28	1.941159	1.120729
	TiC 1/2	460.5	2.91	3.3	2.15	2.786667	0.584836	0.337655
	Ti (IV) 3/2	458.7	7.22	7.88	8.03	7.71	0.430929	0.248797
	Ti (IV) 1/2	464.6	0.79	0.87	0.88	0.846667	0.049329	0.02848
	Ti (II) 3/2	455.5	18.34	16.54	18.1	17.66	0.977343	0.564269
	Ti (II) 1/2	461.4	7.8	6.62	7.53	7.316667	0.61825	0.356947
	Ti (III) 3/2	456.6	37.37	37.5	38.88	37.91667	0.836799	0.483126
	Ti (III) 1/2	462.4	15.89	16.06	16.54	16.16333	0.337095	0.194622

Table S10. Percent Peak Area of Ti 2p, O 1s and C 1s core spectra for Ethanol samples redispersed back into water.

Ethanol then back into water								
	Bonds	Estimated Position	Trial			Peak area		
			1	2	3	Ave	St _{Dev}	ST _{Error}
Titanium	TiC 3/2	454.8	9.48	8.72	9.54	9.246667	0.457092	0.263902
	TiC 1/2	460.5	2.61	2.4	2.63	2.546667	0.12741	0.07356
	Ti (IV) 3/2	458.7	10.31	9.54	9.26	9.703333	0.543722	0.313918
	Ti (IV) 1/2	464.6	2.06	1.43	1.39	1.626667	0.37581	0.216974
	Ti (II) 3/2	455.5	16.95	18.18	17.91	17.68	0.646452	0.373229
	Ti (II) 1/2	461.4	6.79	6.82	7.17	6.926667	0.211266	0.121974
	Ti (III) 3/2	456.6	35.72	36.48	35.92	36.04	0.393954	0.22745
	Ti (III) 1/2	462.4	16.09	16.43	16.18	16.23333	0.176163	0.101708