Supporting Information

MXene Interlayered Crosslinked Conducting Polymer Film for High Specific Absorption of Electromagnetic Interference Shielding

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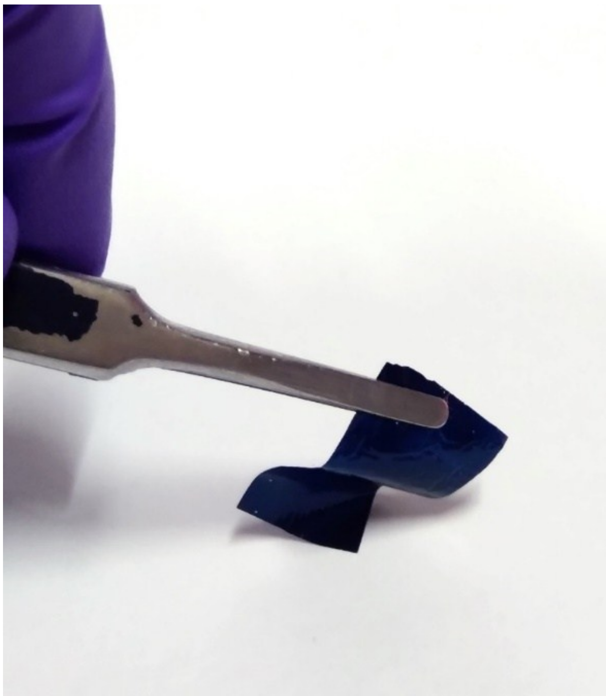


Fig.S1. optical image of the prepared flexible crosslinked PEDOT:PSS-$Ti_3C_2T_x$ MXene nanocomposite film.

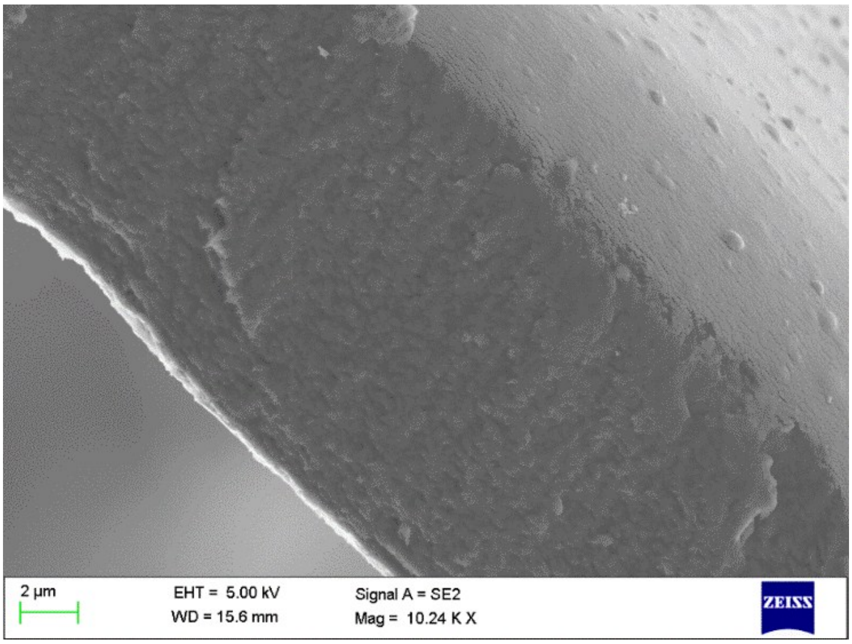


Fig.S2. Cross-section surface morphology of crosslinked PEDOT:PSS film.

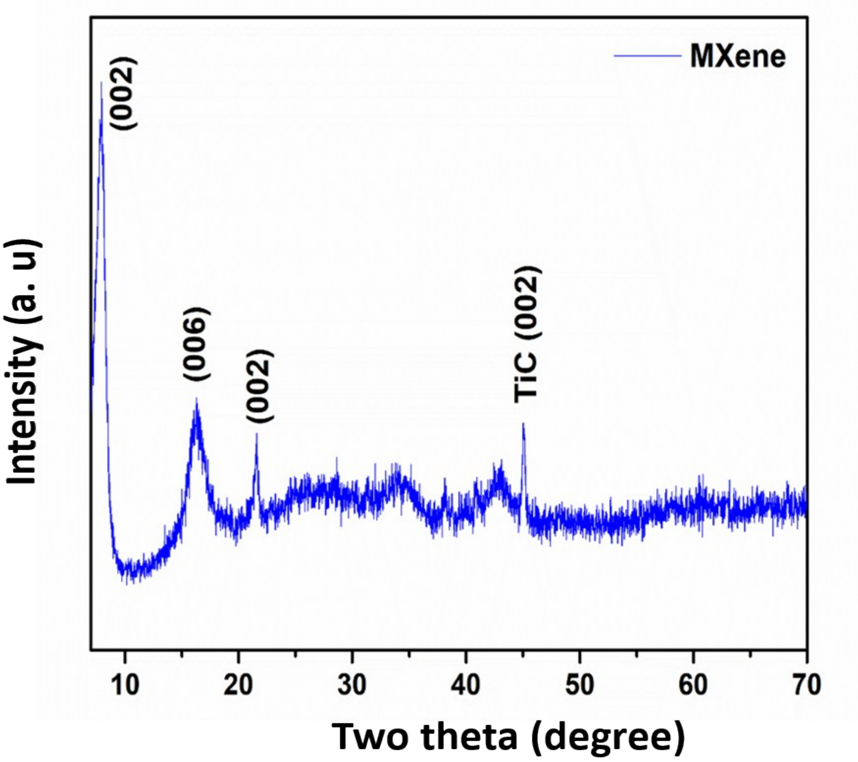


Fig.S3. Powder XRD spectrum of MXene powder

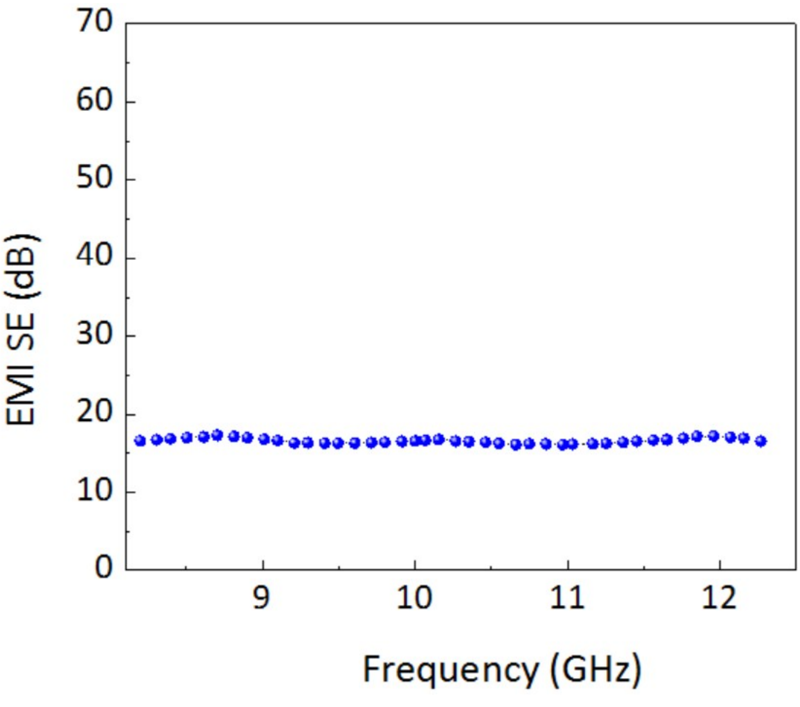
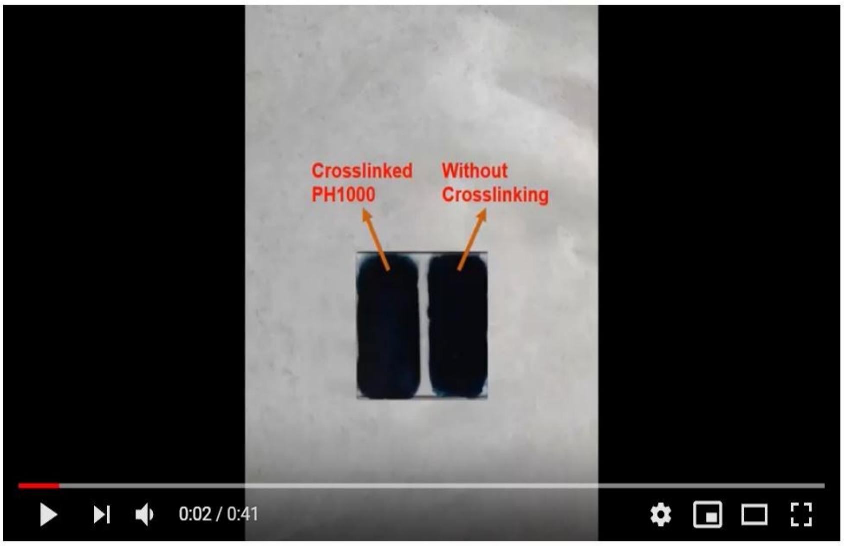


Fig.S4. EMI SE of pristine PEDOT:PSS film (38±2 µm).



Cross -linked PEDOT:PSS film || Water insoluble|| Prepared in ONEGROUP

Fig.S5. A video demonstrating that crosslinked PEDOT:PSS film is water insoluble whereas pristine PEDOT:PSS is water soluble. **Video link:** https://youtu.be/RKcQYObAmT8

Calculation of Specific Shielding Effectiveness (SSE):

SSE value can be obtained by dividing the EMI SE (dB) with density of the film (material),[33] i.e.,

$$SSE = EMI\ SE/density = dB\ cm^3\ g^{-1} \quad (1)$$

However, SSE can't be taken as an intrinsically important parameter for application point of view as it has the basic limitation that it does not account for film thickness. Higher values of SSE can be obtained for higher thicknesses while maintaining low density, which however increases the net weight. Therefore, absolute EMI shielding effectiveness (SSE_t) is a more realistic quantity, which can be expressed as[33]:

$$\text{Absolute EMI SE } (SSE_t) = SSE/t = dB\ cm^3\ g^{-1}\ cm^{-1} = dB\ cm^2\ g^{-1} \quad (2)$$

The films were cut into specific dimension (2.3 cm x 1.0 cm) and weighed on a balance accurate to 0.01 mg. The thickness was determined by SEM. Knowing the volume and weight enabled us to estimate the density. The obtained density was also cross verified by density column measurements. Using equation (1) and (2) SSE and SSE_t values were calculated respectively.

Electrodynamic simulation

The EM simulation was carried out by using Computer Simulation Technology (CST) microwave studio suit (2015), which is a standard high performing electromagnetic simulation software. Finite integration technique (FIT) was used as the foundation technique of CST, which is the integral form of Maxwell's equations. The solution of the equations requires the structure to be subdivided into small cells in frequency or time domain. Two basic solver modules provided in CST microwave studio i.e., time domain solver and frequency domain solver. Time domain solver is used for non-resonant structures, while frequency domain solver contains alternatives for resonant structure. In this work, simulation was carried out using frequency domain solver and standard tetrahedral mesh. Since, only waveguide simulation was carried out, following boundary conditions were assigned (**Figure S6**).

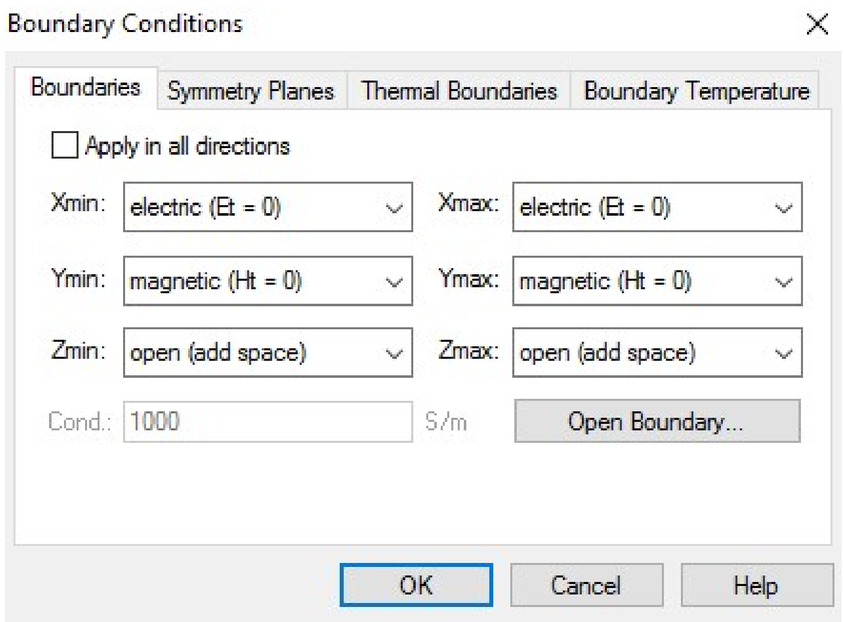


Figure S6. Boundary conditions of EM (waveguide) simulation.

Table S1: Specific EMI shielding performance optimised with thickness of various shielding materials.

Type		Filler	Filler wt%	Matrix	Thickness t (cm)	SE (dB)	SSE (dB cm^{3}g^{-1})	SSE/t (dB cm^{2}g^{-1})
Foam Structures	Carbon Based	rGO	10	PEI	0.23	12.8	44	191.3
		rGO	30	PS	0.2	29	64.4	257.6
		rGO	16	PI	0.08	21	937	11712
		rGO/Fe_3O_4	10	PEI	0.25	18	44	176
		SWCNT	7	PS	0.12	18.5	33	275
		MWCNT	76.2	WPU	0.1	21.1	541	5410
		Carbon	/	PN resin	0.2	51.2	341	1705
		Carbon foam	bulk	/	0.2	40	241	1250
		MWCNT	7	PS	0.18	26.2	243.5	1352
		CNT	0.51#	Cellulose	0.25	40	519	2078
		rGO/ SWCNT	0.28	PDMS	0.2	31	110.7	553.5
		Graphite	/	PLA	0.2	45	64	321.4
	Metal	CuNi	Bulk	/	0.15	25	104	690
		CuNi-CNT	Bulk	/	0.15	54.6	237	1580
		Ag nanowires	4.5	PI	0.5	35	1208	2416
		SS	1.1	PP	0.31	48	75	241.9
	MXene	$Ti_3C_2T_x$ foam	Bulk	/	0.0060	70	318	53030
		MXene aerogel	Bulk	/	/	75	9904	/
		$Ti_3C_2T_x$ aerogel	Bulk	/	0.1	48.5	8818	88182
		$Ti_3C_2T_x$/CA aerogel	Bulk	/	0.0026	54.3	45	17586
Solid Structures	Carbon Based	rGO	7	PS	0.25	45.1	173	692
		rGO/Fe_3O_4	Bulk	/	0.03	24	31	1033
		rGO	25	PEDOT	0.08	70	67.3	841
		MWCNT	20	PC	0.21	39	34.5	164
		MWCNT	15	ABS	0.11	50	47.6	432.7
		MWCNT	20	PS	0.2	30	57	285
		CB	15	ABS	0.11	20	20.9	190
		CB	37.5	EPDM	0.2	18	30.3	15.1
		PDA/AgNP	/	PP	0.035	48.2	209.56	5987
		Biochar	80	UHMWPE/ LLDPE	0.3	48.7	39	130
	Metal	Copper	Bulk	/	0.31	90	10	32.3
		SS	Bulk	/	0.4	89	11	27.5
		Ni fiber	7	PES	0.285	58	31	108.7

		Ni filaments	7	PES	0.285	87	47	164.9
		Al foil	Bulk	/	0.0008	66	24.4	30555
		Cu Foil	Bulk	/	0.001	70	7.8	7812
	MXene	$Ti_3C_2T_x$	Bulk	/	0.0011	68	28.4	25863
		$Ti_3C_2T_x$	90	SA	0.0008	57	24.6	30830
		Crosslinked PEDOT:PSS-$Ti_3C_2T_x$ MXene			0.0006	41	62.5	89924
	Conducting Polymer	PEDOT:PSS without crosslinking	Bulk	/	0.0040	20	30	10916
		Crosslinked PEDOT:PSS	Bulk	/	0.0009	40	70	51480

Table S2. Specific EMI shielding performance optimised with thickness of various shielding materials

Type	Filler	Filler [wt.%]	Matrix	Thickness [mm]	Conductivity [S m^{-1}]	EMI SE [dB]*	Ref
Reduced graphene oxide (rGO)	rGO	7	PS	2.5	43.5	45.1	23
	rGO	10	PEI	2.3	0.001	22	7
	rGO	0.7	PDMS	1	180	30$^{\Diamond}$	34
	rGO	20	Wax	2.0	<0.1	29$^{\Delta}$	35
	rGO	60$^{\#}$	Wax	0.35	2500	27	36
	rGO	7.5	WPU	1	16.8	34	37
	rGO	15	Epoxy	/	10	21	38
	rGO	30	PS	2.5	1.25	29	5
	rGO	10	PU	60	0.06	39.4	39
	rGO	4	PI	0.073	2×10^5	51	9
	rGO	33	PANI	2.8	1800	34.2$^{\Delta}$	40
	S-doped rGO	15	PS	2	33	24.5§	41
	B,N-doped rGO	Bulk	/	1.2	124	42$^{\Delta}$	42
	S-doped rGO	Bulk	/	0.15	3.1×10^4	38.5§	43
	Graphene film	Bulk	/	0.25	/	17$^{\Delta}$	44
	Graphene film	Bulk	/	0.050	1.13×10^4	60	45
	Graphene film	Bulk	/	0.008	10^5	20	46
	Graphene film	Bulk	/	0.015	2.4×10^4	20.2§	47
	Graphene foam	Bulk	/	0.3	310	25	48
	rGO/δ-Fe_2O_3	40	PVA	0.36	3	20.3	36

	rGO/γ-Fe_2O_3	75	PANI	2.5	80	51	49
	rGO/Fe_3O_4	35	PVA	0.3	<0.1	15	50
	rGO/Fe_3O_4	66	PANI	2.5	260	30[∆]	51
	rGO/CF/γ-Fe_2O_3	50	Resin	0.4	1.7 x 10^{4}	41.8	52
	rGO/Fe_3O_4	10	PVC	1.8	7.7 x 10^{-4}	13	53
	rGO/Fe_3O_4	10	PEI	2.5	10^{-4}	18	7
	rGO/MnO_2	Bulk	/	3	/	57[∆]	54
	rGO/Fe_3O_4	Bulk	/	0.25	5000	24	24
	rGO/Fe_3O_4	Bulk	/	3	700	41	55
	rGO-$BaTiO_3$	Bulk	/	1.5	/	41.7	56
	rGO-Ba Ferrite	Bulk	/	1	98	18	57
	rGO/CNT/Fe_3O_4	Bulk	/	2	/	37.5[∆]	58
	CB	15	SEBS	5	22	20	59
	Graphite	25[#]	PA 6,6	3.2	/	12[§]	60
	Graphite	7.05[#]	PE	2.5	10	51.6	61
	Graphite	18.7[#]	PE	3	/	33	62
	Graphite	2	Epoxy	5	2.6	11	63
	Graphite	15	ABS	3	16	6020	64
	MWCNT	76	WPU	0.8	2.1 x 10^{3}	80	65
	CNT	0.66	Epoxy	2	516	33	66
	MWCNT	76.2	WPU	4.5	44.6	50	9
	MWCNT	15	Cellulose	0.15	/	35[◊]	67
	MWCNT	40	PMMA	0.165	1000	27[§□]	68
	MWCNT	15	PEDOT	2.8	1935	58[∆]	69
	MWCNT	10	PTT	2	30	42[∆]	70
	SWCNT	15	Epoxy	2	20	25	71
Carbon Nanotube	SWCNT	20	PU	2	2.2 x 10^{-4}	17	72
	CNT	7	PS	/	/	18.5	8
	CNT	25	Coal tar	0.6	1.1 x 10^{3}	-56	73
	CNT	5	TPU	2	17.9	35.3	74
	CNT	2	UHMWPE	1	21.9	22.7	75
	MWCNT	7	PS	1.8	61.9	42	12
	CNT	3[#]	PDMS/cotton fibre	1.2	/	41	76
	MWCNT	3	Poly lactic acid	2	6.42	31	77
	CNT	5	PPS	2	72	49.6	78
	CNT	4	UHMWPE	1.6	30.1	32.6	79
	CF/Fe_3O_4	10	Epoxy	13	0.2	20	80
	CF/Fe_3O_4	5	PDMS	0.7	710	67.9	81
	CF	40[#]	PES	2.87	/	38[§]	82
Carbon Fiber	CF	10	PVDF	0.05	180	14[◊]	83
	CF	10[#]	PP	3.2	10	25	84
	CF	15	PS	/	0.1	19	85
	CF/CNT	13	PS	1	0.215	21.9[∆]	86
	CF-GN	17.2	Wax	0.27	800	28	87
	Vapour grown CF	5	PANI/DBSA/DVB	2	189	51	88

Metals	Ni	10#	PP	3	100	20	89
	Ni/CB	50	Resin	1	31.6	85	90
	Ni	40#	PVDF	1.95	<0.1	23	91
	Ni Fiber	7#	PES	2.85	/	58§	32
	Ni-Co Fiber	30	Wax	2.5	1.3 x 10^3	41	92
	Ag/CF	4.5	Epoxy	2.5	/	38	93
	Ag Nanowires	75	Epoxy	0.04	4.7 x 103	35	94
	Ag Nanowires	14#	PANI	0.013	5.3 x 10^5	50	95
	Ag Nanowires	2.5#	PS	0.8	1.9 x 10^3	33	96
	Cu/Graphite	20	PVC	2	80	70	97
	Cu Nanowires	2.1#	PS	0.2	/	35	98
	Al Flakes	20#	PES	2.9	/	39§	82
	SS	1.1#	PP	3.1	0.1	48	18
	SS	10#	PES	3.08	/	35	82
	SS	Bulk	/	4	/	89§	32
	Copper	Bulk	/	3.1	/	90§	32
	Cu Foil	Bulk	/	0.010	8.0 x 10^7	70	33
	Al Foil	Bulk	/	0.008	2.8 x 10^7	66	33
	Flexible graphite	Bulk	/	3.1	1.351 x 10^5	130	99
	Flexible graphite	Bulk	/	0.79	1.351 x 10^5	102	99
	Carbon Foam	Bulk	/	2	2.4 x 10^2	51.2	10
	Carbon Foam	Bulk	/	2	126.5	40§	11
	MoS_2	30	Glass	1.5	100	24.2	100
	MoS_2	60	Wax	2.4	2.2 x 10^{-5}	-38(RL)	101
	rGO-SiO_2	Bulk	/	1.5	33	38	102
	Ni Ferrite	/	PVDF	2	/	67	103
	Fe_2O_3/ash	60	PP	2	1	25.5	104
	Carbon Aerogel	Bulk	/	10	133.3	51	105
	Ba Ferrite	38.2	PPY	2	>1	12	106
	Ba Ferrite*	/	PEDOT	/	/	22.5$^{\Delta}$	107
	Zn Ferrite	50	PPY	2.7	/	-29 (RL)	108
	Mn Ferrite	15	PPY	1.5	/	-12 (RL)	109
	Fe_2O_3	/	PEDOT	6	40	22.8	110
	Fe_3O_4	40	PANI	2	/	-33 (RL)	111
	Carbonyl iron	50	PPY	2.2	/	-39(RL)	112
	Carbonyl iron	20	PVDF/5%CB	2	/	27	113

	$Mo_2TiC_2T_x$	Bulk	/	0.004	1.0 x 10^4	23	33
	$Mo_2TiC_3T_x$	Bulk	/	0.0035	2.5 x 10^4	26	33
	$Ti_3C_2T_x$	Bulk	/	0.045	4.8 x 10^5	92	33
Conducting Polymer	P3HT	Bulk	/	5.31 x 10^{-3}	5.412 x 10^{-3}	-44.4(RL)	114
	Polyaniline nanofibers	Bulk	/	5 x 10^{-2}	1850	74 $^{\Delta}$	115
	Polypyrrole	40	PVC	/	~5	19 $^{\Delta}$	116
	PEDOT:PSS	Bulk	/	0.038	15	17	This work
	Crosslinked PEDOT:PSS-MXene	Bulk	/	0.006	38800	41	This work

* Values in bracket indicate maximum EMI SE value in measured range. EMI SE is obtained mainly in X-band (8.2 to 12.4 GHz), except otherwise specified; / - values not provided; # - Vol. %; RL - Reflection loss; SS - Stainless steel; Bulk - 100% pure material with no polymeric binder; Δ - Ku-band (12.4-18 GHz); § - L and S-band; 1-4 GHz; ◊ - Ultra high frequency (UHF); □-C band.

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