Supplementary Information (SI) for Materials Horizons.

Supplemental Information

Multifunctional Strain-activated Liquid-metal Composite Film with Electromechanical Decoupling for Stretchable Electromagnetic Shielding

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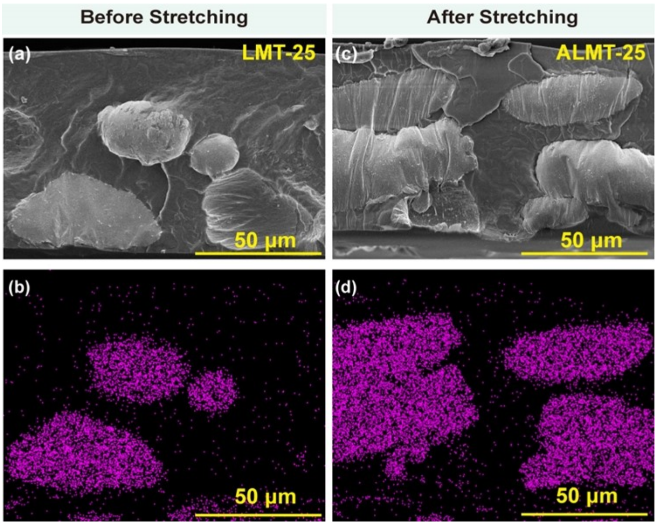

Figure S1. SEM images of LMT-25 (a, b) and ALMT-25 (c,d) with corresponding EDS elemental mapping results for Ga.

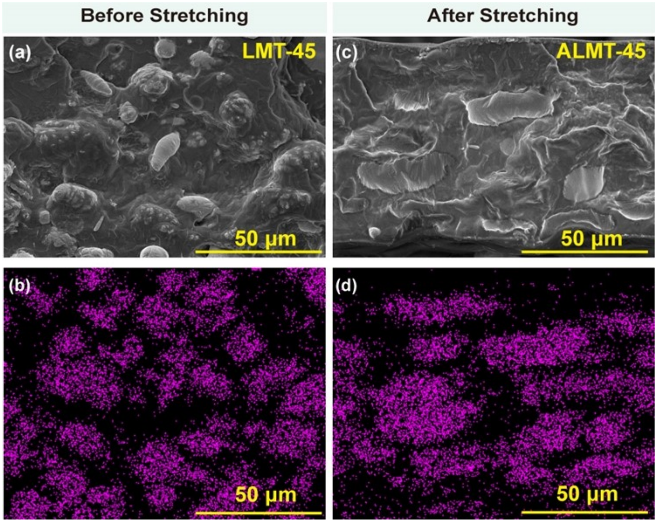

Figure S2. SEM images of LMT-45 (a, b) and ALMT-45 (c,d) with corresponding EDS elemental mapping results for Ga.

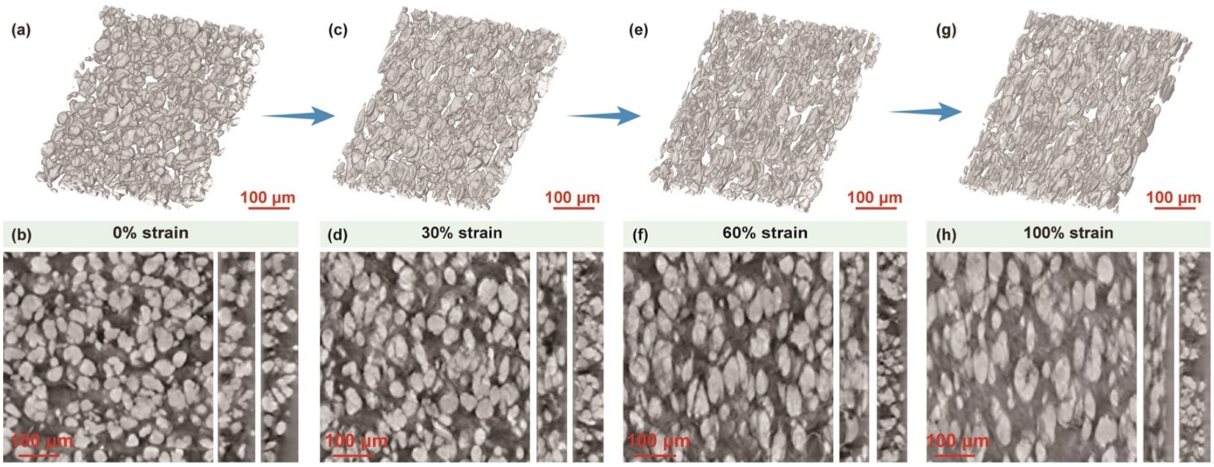

Figure S3. Micro-CT image of LMT-35 during stretching.

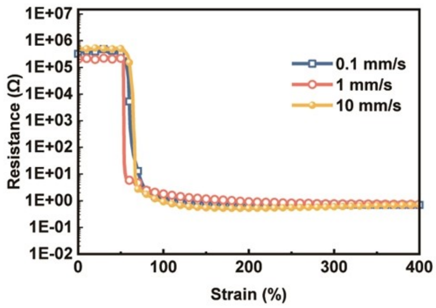

Figure S4. Resistance versus strain of LMT-35 (rate = 0.1, 1, and 10 mm/s).

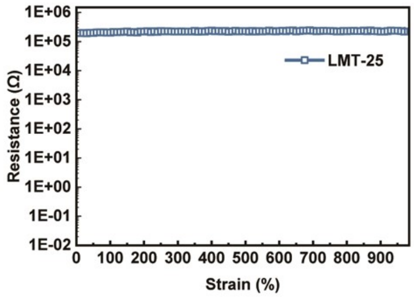

Figure S5. Resistance versus strain of LMT-25 (rate = 0.1 mm/s).

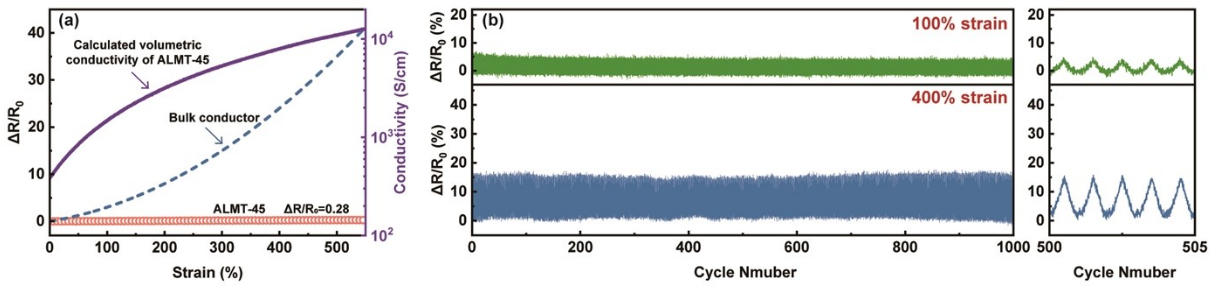

Figure S6. (a) Relative change in resistance and corresponding volumetric conductivity of ALMT-45 under strains of up to 550%, and theoretical relative change in resistance of the bulk conductor. (d) Relative change in resistance of ALMT-45 over 1000 cycles to 100% and 400% strain.

Assume that the resistance, thickness, widths, length, volume, electrical resistivity, and conductivity of the sample at time t is R_t, T_t, W_t, L_t, $V_t = W_t T_t L_t$, ρ_t, and σ_t, respectively.

At $t = 0$,

$$R_0 = \frac{\rho_0 L_0}{S_0} = \frac{\rho_0 L_0}{W_0 T_0} = \rho_0 \frac{L_0^2}{V_0} = \frac{1}{\sigma_0} \frac{L_0^2}{V_0}$$

At $t = t$,

$$\varepsilon_t = \frac{L_t - L_0}{L_0}$$

$$R_t = \frac{\rho_t L_t}{W_t T_t} = \rho_t \frac{L_t^2}{V_t} = \frac{1}{\sigma_t} \frac{L_t^2}{V_t} = \frac{1}{\sigma_t} \frac{(1 + \varepsilon_t)^2 L_0^2}{V_t}$$

$$\frac{R_t}{R_0} = \frac{\sigma_0 V_0}{\sigma_t V_t} (1 + \varepsilon_t)^2$$

The volume of the sample is assumed to be constant during stretching ($V_0 = V_t$),

$$\frac{R_t}{R_0} = \frac{\sigma_0}{\sigma_t}(1+\varepsilon_t)^2$$

(a) If the conductivity of the sample remains constant during stretching ($\sigma_0 = \sigma_t$),

$$\frac{R_t}{R_0} = (1+\varepsilon_t)^2$$

(b) If conductivity changes with strain,

$$\sigma_t = \frac{\sigma_0(1+\varepsilon_t)^2 R_0}{R_t}$$

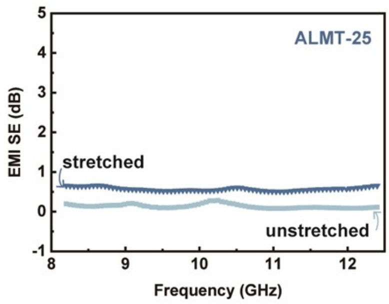

Figure S7. The EMI SE curves of ALMT-25.

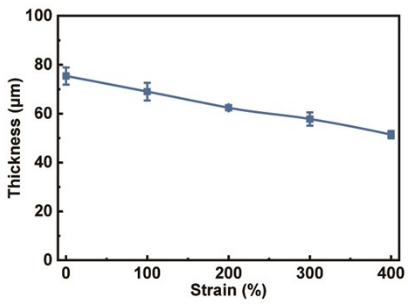

Figure S8. Thickness variation of ALMT-35 under different strains.

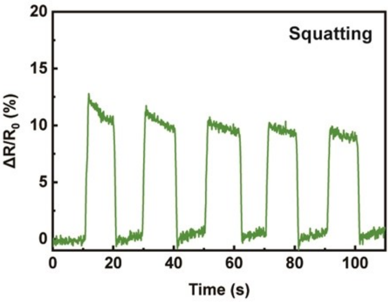

Figure S9. Relative resistance change of the ALMT sensor at the knee joint during squatting.

Table S1. Comparisons of stretchable conductors reported in recent literature.

Type	Filler	Matrix	εmax	σ0 (S/cm)	ΔRt/R0 at max strain	σt (S/cm)	QF	Ref.
Liquid metal fillers	EgaInSn (35 vol%)	TPU	700%	266	0.57@700%	14000@700%	12@700%	**This work**
	EGaInSn (45 vol%)	TPU	550%	378	0.28@550%	12700@550%	20@550%	
	EGaInSn and Fe particles	Ecoflex	600%	/	/	25000@400%	/	1
	3D EGaIn network	Ecoflex	510%	5300	/	11000@510%	/	2
	EGaIn	SBS	1800%	100	0.04@1800%	/	2-441@1800%	3
	EGaIn	VHB	~1200%	20600	~3.5 @1200%	/	~3.4@1200%	4
	EGaIn + Ag	SIS	~1200%	8210	40~70 @1200%	/	0.3~3@1200%	5
	EGaIn	11-PUA	744%	2500	0.85@700%	20000@700%	8.2@700%	6
	EGaIn	TPU	1000%	4200	20@1000%	11100@300% 3800@1000%	0.5@1000%	7
	EGaIn	TPU	2260%	22532	0.34@1000% 1.59@1600% 31.6@2266%	/	29.4@1000% 10.06@1600% 0.74@2266%	8
	EGaIn	TPU	4100	21000	19.8@4100%	/	9.3@4100%	9
	EGaIn	PVDF	740%	435	4@740%	/	1.85@740%	10
	EGaIn + Ag	EVA	1000%	8331	10@1000%	/	1@1000%	11
	EGaIn + Ag	SIS	100%	6380	6.78@1000%	/	1.47@1000%	12
	EGaIn + Ag	PUA	2500%	6250	9@2500%	/	2.78@2500%	13
	EGaIn + Ni	P(AAm-co-MAAc)	630%	2000	5.4@630%	/	1.17@630%	14
	EGaIn	SEBS	900%	34000	39@700%	/	0.2@700%	15
	EGaIn	PVP	800%	6900	60@800%	100	~0.13@800%	16
	EGaIn	SIS	2500%	30000	37@2500%	/	~0.68@2500%	17
Rigid metal fillers	AgNPs	SEBS	180%	11.4	1.05@180%	84.6@180%	1.7@180%	18
	Ag flakes	Fluorine rubber	215%	738	~39.2@215%	~180@215%	~0.055	19
Rigid metal fillers	Ag flakes	Fluorine rubber	400%	4000	~106 @ 400%	950@400%	~0.038	20
	Ag flakes	PAAm alginate hydrogel	250%	374	70 @250%	/	~0.036	21
	Ag flakes	Ecoflex	1780%	~133	153 @ 1780%	/	~0.12	22
	AuNPs	TPU	115%	11000	~20.2 @115%	210@110%	~0.057	23
	AgNW	PNIPAM	800%	93	3@700%	/	~2.3@700%	24
	AgNW/Au	SBS	840%	30000	~2649 @840%	3000@840%	~0.003	25
	Cu	rubber	100%	215	/	2@100%	/	26

Type	Filler	Matrix	εmax	σ0 (S/cm)	ΔRt/R0 at max strain	σt (S/cm)	QF	Ref.
Carbon materials	CNT+AgNW	PVDF	140%	5710	~1306 @140%	20	~0.001@140%	27
	CNT	Fluorine rubber	118%	10	~3.75@118%	10	~0.3@118%	28
	CNT	Fluorine rubber	134%	57	~51@134%	6	~0.026@134%	29
	CNT	PDMS	150%	1100	4@150%	/	0.375@150%	30
	CNT	PU	300%	0.05-1	3.2@300%	/	0.9@300%	31

SBS: poly(styrene-block-butadiene-block-styrene

VHB: 3M VHB tape

SIS: Styrene–isoprene block copolymers

11-PUA: 11-(phosphonoundecyl)acrylate

PVDF: polyvinylidene difluoride

EVA: Ethylene-Vinyl Acetate

PUA: polyurethane acrylate

P(AAm-co-MAAc): Poly(acrylamide-co-methacrylic acid)

SEBS: poly[styrene-b-(ethylene-co-butylene)-b-styrene]

PVP: Polyvinyl pyrrolidone

PAAm: polyacrylamide

PAM: Polyacrylamide

PNIPAM: poly(N-isopropyl acrylamide)

PU: polyurethane

Table S2. Comparisons of stretchable EMI shielding materials reported in recent literature.

Type	Filler	Matrix	Strain (%)	Thickness (mm)	SE (dB)	SSE (dB /mm)	Ref.
Liquid metal fillers	EgaInSn (35 vol%)	TPU	0-400%	0.075-0.051	58.1-63.8	774-1241	**This work**
	EgaInSn (45 vol%)	TPU	/	0.094	80.9	860.6	
	EGaInSn and Fe particles	Ecoflex	0-400%	0.8-0.2	20.6-80.7	25.8-404	1
	3D EBiInSn network	Ecoflex	0-400%	2-3.6	57.0-85.0	15.8-42.5	32
	3D EGaIn network	Ecoflex	0-400%	2-1	41.5-81.6	20.8-81.6	2
Liquid metal fillers	EGaIn	PDMS	0-50%	2.4	50.0-43.5	20.8-18.1	33
	EGaIn	PDMS	0-100%	3	~37.0	12.3	34
	EGaInSn	PDMS	0-75%	0.15-0.11	43.2-44.2	288-401	35
	EGaInSn	PDMS/Textile	0-50%	0.35	72.6-52.4	149.7-207.4	36
	EGaIn and CNT	PAM and gelatin	0-200%	1-0.22	17.7-37.4	17.7-170.0	37
	ESnBi	PVDF	/	2	68.8	34.4	38
	EGaIn	CNF	/	0.1	40.5	405.0	39
	EGaIn	EM	/	1	90.6	90.6	40

Type	Filler	Matrix	Strain (%)	Thickness (mm)	SE (dB)	SSE (dB /mm)	Ref.
	EGaIn and Ag NPs	SEBS	300%	0.2	73.5	367.5	41
	EGaIn foam	/	/	5	65.0	13.0	42
Rigid metal fillers	AgNPs	SEBS	0-100%	2.84	28.0-55.0	19.4-9.9	18
	AgNWs	PU	0-30%	0.6	63.9-56.2	106.5-93.7	43
	Cu	rubber	0-75%	0.4	35.7-10.7	89-26.7	26
Carbon materials	CNT	PU	0-30%	2.9	36.4-20.2	12.6-7.0	44
	CNT	TPU	0-200%	2-1.56	34.6-12.8	17.3-8.2	45
	rGO	PDMS	0-100%	2.4	25.0-18.0	10.5-7.5	46
	MXene	PU	0-30%	0.2	22.0	105.0	47
	MXene	TPU	0-70%	0.3	31.4-22.0	104.7-73.3	48

PDMS: Polydimethylsiloxane
CNF: Cellulose nanofibers
EM: expandable microsphere

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