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Recent advances in multimodal mechanoluminescent sensors enabled by nanostructure design

Zihao Wang,[a] Jiaman Hu,[a] Minglin Yang,[a] Jize Liu*[a] and Xinxing Zhang*[b]

[a] School of Materials Science and Engineering, Hainan University (Haikou, 570228, Hainan, China)
[b] State Key Laboratory of Polymer Materials Engineering, Polymer Research Institute, Sichuan University (Chengdu, 610065, China)

*Corresponding authors: Jize Liu(E-mail address: ljz@hainanu.edu.cn); Xinxing Zhang(E-mail address: xxzwwh@scu.edu.cn)

Table S1 Mechanoluminescence coupled with piezoresistive-response

Examples	Materials	Structures	Sensing mechanisms	Performance
Ref. 58	Polyaniline/metal-doped zinc sulfide/polydimethylsiloxane	microcrack structured layer/mechanoluminescent substrate	generation of mechanical microcracks under strain	gauge factor up to 33.8 with a stretchability of 70%
Ref. 59	carbon nanotubes/fluorescein	strain-dependent microcracks structure upon elastomer	generation of mechanical microcracks under strain	resistance improved approximately fourfold within 10 ms
Ref. 60	Layer structure graphene/$SrAl_2O_4$:Eu^{2+}, Dy^{3+}/polyurethane	reduced graphene oxide deposited on cotton fabric /mechanoluminescent polyurethane foamed coating.	controllable positive/negative piezoresistivity and mechanoluminescent coating	gauge factor from −2.5 to 17
Ref. 61	polyurethane / silver nanowires/ MXene/Silica-modified $SrAl_2O_4$:Eu^{2+}, Dy^{3+}	core–shell nanostructured smart fiber	The strong interfacial interactions between fiber layers results in high sensitivity	gauge factor 12383500

Table S2 Mechanoluminescence coupled with triboelectric-response

Examples	Materials	Structures	Sensing mechanisms	Performance
Ref. 30	Cr^{3+}-doped zinc gallogermanate/polydimethylsiloxane	The triboelectric nanogenerators	trap-controlled luminescence and interfacial electron transfer	Increased force applied in the 0-1 N range produced voltage (0-1V) and ML intensity (1×10^5 CPS).
Ref. 68	organic ML materials (Cz-A6-dye)/ polyacrylamide (PAAm)-LiCl hydrogel/ polycarbonate/Poly dimethylsiloxane	organic ML layer/ electrode/ substrate /triboelectrification layer	interfacial electron transfer	High luminance (130% enhancement) and low threshold pressure (57% reduction)
Ref. 69	Polydimethylsiloxane/ silver nanowires/ single-electrode TENG; ZnS	transparent single-electrode triboelectric nanogenerator with a ZnS based mechanoluminescence composite.	Input stimulus signal was converted into output of optical/electrical signals by a periodic contact/separation motion between PDMS film and finger pulp	high output of V_{oc} = 70 V and J_{sc} = 1.5 mA m^{-2}. .
Ref. 70	carbon nanotube fiber; ZnS:Cu	The fiber sandwiches the carbon nanotube fiber (CNTF) electrode between the core layer of stretchable silicone foam bars and an Ecoflex/ZnS:Cu ML encapsulated layer	electric field-induced charge polarization of the ZnS:Cu fluorescent material during pressure deformation.	ML TENGF fiber demonstrates a remarkable non-contact distance of up to 35 cm
Ref. 40	ZnS:Cu; polydimethylsiloxane;	a fully self-powered mechanoluminescent-triboelectric bimodal sensor based on micro-	triboelectric nanogenerator for power supply of the ML sensor	a microstructured surface improved triboelectric performances (voltage increases from 8 to 24 V).

		nanostructured mechanoluminescent elastomer		
Ref. 71	$SrAl_2O_4:Eu^{2+}:Dy^{3+}$; polyvinylidene-fluoride-co-hexafluoropropylene	mechanoluminescent/triboelectric hierarchical structure	triboelectric nanogenerator for power supply of the ML sensor	low force detection limit (0.082 N), high sensitivity (9.69 a.u. N−1), fast response (35 ms), and good reliability (5000 cycles)

Table S3 Mechanoluminescence coupled with temperature- or humidity-response

Examples	Materials	Structures	Sensing mechanisms	Performance
Ref. 84	ZnS–CaZnOS/ poly(3,4-ethylenedioxythiophene):poly(styrene sulfonate) (PEDOT:PSS)	The temperature sensor composed of a PEDOT:PSS film and copper interdigital electrode is sandwiched between two luminescent layers with ML hybrids embedded in the acrylic polymer	The combined sensing mechanisms of piezo/tribophotonic and thermoresistive effects enable the independent transduction of mechanical and thermal stimuli into optical and electrical signals	The temperature sensitivity was -0.6% $°C^{-1}$, and the force detection limit was 2 N
Ref. 31	SrZnSO:Tb,Eu	hexagonal system (space group P63mc)	piezoresponse and polarization switching behavior	stress–temperature dual-modal imaging method was constructed based on the changes in stress-responsive integral intensity and temperature-responsive IR.
Ref. 59	3-aminophenylboronic acid; epoxidized natural rubber; carbon nanotubes; cellulose nanocrystals	a skin-like material via constructing a strain-dependent microcracks structure upon synergistic dynamic-covalent and hydrogen bonds-crosslinked supramolecular elastomer	When the environmental humidity changes, the water molecules can easily diffuse into the conductive network and thereby give rise to the variation of electric resistance	materials exhibit reversible straindependent luminescence and sensitive resistance response to external stimulus, such as tensile strain and humidity.