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Supplementary Information

Printed flexible mechanical sensors

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Table S1 Summary printed flexible mechanical sensors

Type of sensor	Printing techniques	Printed materials	Substrate	Printed parts	Printer	Resolution	Ref.
Strain	Aerosol jet printing	PRELECT TPS R©, Clariant AgNP ink	Kapton© PI	Sensing element	Optomec aerosol jet 5X system	10μm	1
Strain	Aerosol jet printing	PEDOT:PSS	PEI	Sensing element	Customized aerosol printing system	500μm	2
Strain	Digital light processing, direct ink writing	DLP: GMA, Ebecryl 8804, isodecyl acrylate DIW: GMA, Ebecryl 8804, AgNP ink	Printed elastomer	DLP: substrate DIW: sensing element, circuit	Customized hybrid printer	DIW: 100μm DLP: 30μm	3
Strain	Digital light processing	HEA and IBOA resin	—	Sensing element	SprintRay Pro	95μm	4
Strain	Digital light processing	RGO/elastomer resin	—	Sensing element	B9 Core 550	25μm	5
Strain	Direct ink writing	MWCNTs, Ecoflex 0030, Si NPs	PDMS	Sensing element, electrodes	Customized 3D printing system	—	6
Strain	Direct ink writing	TPU, CNPs	PC	Sensing element	Anet A8	10μm	7
Strain	Direct ink writing	Indium-tin oxide (ITO)	PET, polyimide	Sensing element	Customized printer	100μm	8
Strain	Fused filament fabrication	TPU, ABS/CB	—	TPU: matrix ABS/CB: microchannels	Customized dual extruder printer	—	9
Strain	Fused filament fabrication	NinjaFlex, conductive PLA	NinjaFlex	NinjaFlex: matrix PLA: sensing element	Lulzbut TAZ 5	50μm	10
Strain	Fused filament fabrication	CBPs/TPU composite	TPU	Sensing element, electrodes	Multi-material FDM 3D-printer	100μm	11
Strain	Fused filament fabrication	GNPs/TPU	TPU	Sensing element	MakerBot Replicator 2	100μm	12

Strain	Fused filament fabrication	Conductive TPU	TPU	Sensing element	Prusa i3 MK3	12.5μm	13
Strain	Fused filament fabrication	TPU/MWCNT	—	Sensing element	Customized FDM printer	11μm	14
Strain	Fused filament fabrication	MWCNT/GNP/TPU	—	Sensing element	ET-K1	11μm	15
Strain	Fused filament fabrication	CNT/GNP/TPU	—	Sensing element	ET-K1	11μm	16
Strain	Inkjet printing	Ag ink	PUA	Electrodes	Customized printer	20μm	17
Strain	Inkjet printing	Conductive silicon rubber (CSR)/silver-coated-glass fiber (AGF)/carbon fibers (CF)	PDMS	Sensing element, circuit	Customized e-3DP printer	—	18
Strain	Inkjet printing	Ag ink	Woven fabrics textile	Sensing element, circuit	Fujifilm Dimatix DMP-2850	25μm	19
Strain	Inkjet printing	Projet's VisiJet composite	—	Microchannels	ProJet 5500X inkjet printer	13μm	20
Strain	Inkjet printing	SunTronic ink	Kapton© PI	Sensing element	Fujifilm Dimatix DMP 2831	25μm	21
Strain	Inkjet printing	CNT/PDMS, Ag paste	Kapton© polyimide	Sensing element, electrodes	Fujifilm Dimatix DMP 2831	25μm	22
Strain	Screen printing	MWCNTs/WPU	WPU	Sensing element	—	—	23
Strain	Screen printing	PVC/CB	Polyimide	Electrodes	—	—	24
Strain	Screen printing	CB/AgNP	PET	Sensing element	Samborn screen	—	25
Strain	Screen printing	PDMS/pPVC/CNFs	Commercial textile CPNs	Sensing element	—	—	26
Strain	Screen printing	AgNWs ink	PET	Sensing element	Nylon screen	—	27
Strain	Screen printing	Heptane-graphite ink	PDMS, Sylgard 184	Sensing element	—	—	28

Pressure	Digital light processing	Acrylamide/AA (99%)/MgCl2·6H2O, PEGDA/TPO	PET	Sensing element	Ruiyi, Han'Laser	50μm	29
Pressure	Digital light processing	PUA resin	PET	Sensing element	Commercial DLP-based 3D printer	400μm	30
Pressure	Direct ink writing	Pr-GO/NaOH	Glass	Microstructure	Fisnar F5200n	1μm	31
Pressure	Direct ink writing, inkjet printing	DIW: elastic silica gel Inkjet: Ag ink	PET	Inkjet: electrodes DIW: dielectric layer	Customized single desktop printer	—	32
Pressure	Direct ink writing	DOWSIL™ SE 1700 Silicone Elastomer/PDMS	Silicon wafer	Dielectric layer	Customized DIW 3D printer	—	33
Pressure	Direct ink writing, Digital light processing	MWCNT/PDMS	PDMS	DLP: substrate DIW: sensing element	Customized DIW 3D printer	—	34
Pressure	Direct ink writing	Graphene coated TPU/CNFs	TPU	Sensing element	350PCS-SM200OMEGAX	—	35
Pressure	Direct ink writing	CB/PDMS, PDMS	—	Substrate, sensing element	Multi-material 3D printer	—	36
Pressure	Direct ink writing	MWCNT/PDMS, Ag ink	PDMS	MWCNT/PDMS: sensing element Ag ink: electrodes	Customized DIW 3D printer	—	37
Pressure	Direct ink writing	PDMS/EGO ink	SU-8 coated silicon wafer	Sensing element	nScrypt 3Dn-300	10nm	38
Pressure	Inkjet printing	Ecoflex 0020 silicone elastomer/CNTs/SiNPs	—	Entire sensor	Customized 3D printing system	—	39
Pressure	Inkjet printing	Ag ink, aluminum-doped zinc oxide ink	Glossy photo-paper	Entire sensor	Commercial inkjet printer	—	40
Pressure	Inkjet printing	GO ink	Polyimide	Sensing element	Customized printer	—	41
Pressure	Inkjet printing	AgNPs ink	Kapton® HN or Kapton® Black	Electrodes	Dimatix DMP-2800	25μm	42
Pressure	Inkjet printing	PEDOT:PSS/PUD, AgNPs	PDMS	Electrodes	—	—	43
Pressure	Inkjet printing	MWCNT ink	Aramid nanofibers	Sensing element	HP Deskjet 1112	20μm	44

Pressure	Inkjet printing	Ag ink	Polyethylene naphtholate	Electrodes	Dimatix inkjet DMP—2800	25μm	45
Pressure	Screen printing	AgNWs, TEMs/PDMS composite ink	hydrophilic PET	AgNWs: electrodes TEMs/PDMS: dielectrics layer	—	—	46
Pressure	Screen printing	Laser-induced graphene (LIG) ink	PDMS	Electrodes	—	—	47
Pressure	Screen printing	Nano-Ag ink	PET	Electrodes	OS-500FB	—	48
Pressure	Screen printing	Ag ink, PDMS	PET	Ag ink: electrodes PDMS: dielectric layer	HMI 485 Semi-Automatic Screen printer	—	49
Pressure	Screen printing	Conductive CNT ink	PDMS	Electrodes	AMI MSP 485	—	50
Pressure	Screen printing	Conductive CNT ink	AgNW/TPU	Electrodes	—	—	51
Pressure	Screen printing	PANI/COOH-MWCNTs/Ni NPs paste	Cotton fabric	Sensing element	Nylon wire	—	52
Pressure	Screen printing, inkjet printing	Screen printing: PEDOT:PSS & P(VDF-TrFE) Inkjet: AgNPs ink	Polyethylene naphtholate	P(VDF-TrFE): sensing element PEDOT:PSS & AgNPs ink: electrodes	MT320T, Fujifilm Dimatix DMP2831	25μm	53
Pressure	Screen printing	Ag, laser-induced graphene (LIG), PDMS	PET, polyimide	Electrodes, sensing element	—	—	54
Pressure	Screen printing	Ag ink, PEDOT:PSS	Ag ink: PDMS/PET PEDOT:PSS: tissue paper	Ag ink: electrodes PEDOT:PSS: sensing element	—	—	55
Pressure	Electrohydrodynamics printing	AgNP-based ink	Teslin	Sensing element	Homemade EHD printing system	—	56
Force	Aerosol jet printing	AgNP ink, PI ink	Kapton© polyimide	Electrodes	Aerosol Jet 200	25μm	57
Force	Digital light processing	SP-RF0900/Ebecryl 110	—	Substrate	DLP-based printing system	—	58
Force	Digital light processing	PEDOT:PSS/PUA	—	Sensing element, electrodes	M-Jewelry U50	50μm	59

Force	Direct ink writing	PDMS MPs/PDMS-CNTs	—	Sensing element	—	—	60
Force	Direct ink writing	PDMS/Graphene, PDMS	—	Sensing element	Commercial 3D printer	—	61
Force	Direct ink writing	PDMS/ barium titanate, MWCNTs	—	MWCNTs: electrodes PDMS/BTO: sensing element	Hyrel 30 M printer	5μm	62
Force	Direct ink writing	SE 1700, Ecoflex 0030, silica NP, NdFeB	—	Sensing element	Customized printer	100μm	63
Force	Direct ink writing, inkjet printng	Inkjet: Ag ink DIW: silicone ink	PET	Ag ink: electrode Silicone ink: dielectric layer	Customized Prtronic microelectronic printer	20μm	64
Force	Fused filament fabrication	PI/ETPU/ NinjaFlex	—	NinjaFlex: Dielectric layer PI/ETPU: electrodes	FlashForge Creator Pro	200μm	65
Force	Fused filament fabrication	PI/ETPU 95–250 CB	Ninjaflex	Sensing element	FlashForge Inventor	11μm	66
Force	Fused filament fabrication, stereolithography	FDM: polylactic acid—PLA, SLA: HTM 140	—	Sensing element	FDM: RepRap Prusa I3 SLA: Perfactory Micro EDU	FDM: 400μm SLA: 150μm	67
Force	Fused filament fabrication	CNT/ TPU, ABS	—	Sensing element	Makerbot 2X replicator	11μm	68
Force	Fused filament fabrication	TPU, carbon based PLA	TPU	TPU: dielectric layer Carbon based PLA: electrode, sensing element	Ultimaker s5	6.9μm	69
Force	Fused filament fabrication	Carbon doped TPU, PLA	—	Sensing element	Diabase H-Series Hybrid	5μm	70
Force	Fused filament fabrication	CNT/GNP/TPU CPCs	TPU	Sensing element	Commercial FFF printer	—	71
Force	Inkjet printing, transfer printing	MWCNT	PET, PDMS	Sensing element	HP Envy 4501	20μm	72
Force	Inkjet printing	P(VDF-TrFE-CTFE) terpolymer	Polyimide	Sensing element	PiXDRO LP50	15μm	73
Force	Inkjet printing	PEDOT/PSS	Transparent high-	Sensing element	Dimatix DMP-3000	5μm	74

			temperature resin				
Force	Inkjet printing	DGP 40LT-15C Ag ink	PET	Electrodes	Dimatix DMP-2850	25μm	75
Force	Screen printing	Copper/conductive adhesive	PET	Electrodes	—	—	76
Force	Screen printing	Ag paste, P(VDF-TrFE)/MWCNT/PDMS composites	Polyimide	Ag paste: electrode P(VDF-TrFE)/MWCNT/PDMS composites: sensing element	—	—	77
Force	Screen printing	Conductive copper adhesive	Flexible printed circuit board, PET	Electrodes	—	—	78
Force	Screen printing	Ag ink, AgNP/CNT	PET	Electrodes	—	—	79
Force	Screen printing	Ag ink	PET	Electrodes	—	—	80
Force	Screen printing	PVDF, Ag ink	PET, paper	Electrodes, circuit	—	—	81
Force	Screen printing	Ag 800, PDMS	Kapton® 500HN, polyimide	Ag 800: electrodes PDMS: dielectric layer	AMI MSP 485	—	82
Force	Dispenser printing	MWCNTs	—	Electrodes	Customized printer	100nm	83
Force	Dispenser printing	Ag/silicone elastomer	Glass	Sensing element	Customized 3D printer	—	84

Table S2. Comparison of printed flexible force sensors

Printing technology	Active material	Range	Sensitivity	Sensing principle	Ref.
FFF	Carbon doped conductive TPU	1-10N	Not consistent	Piezoresistive	49
DLP	PEDOT: PSS	0-4N	1500 ohm/N*	Piezoresistive	59
Screen printing	MWCNT/PDMS	0-10N	20 kiloohm/N	Piezoresistive	77
Screen printing	Polyvinylidene fluoride trifluoroethylene [P(VDF-TrFE)]	0.5-4N	0.05 V/N	Piezoresistive	77
DIW	MWCNT/TangoPlus	0-20N	0.175V/N*	Piezoresistive	83
Screen printing	Conductive rubber	0-0.6N in x-axis 0-0.6N in y-axis 0-15N in z-axis	0.471 V/N in x-axis 0.466 V/N in y-axis 0.201 V/N at 0-6N and	Piezoresistive	76

			0.067 V/N at 6-15N in z-axis		
Screen printing	Silver	0-1.4N	1.2 V/N	Piezoelectric	81
Screen printing	Conductive rubber	0-1N in x-axis 0-1N in y-axis 0-3N in z-axis	1.59 V/N in x-axis 1.49 V/N in y-axis 1.87 V/N at 0-6 N and 0.47 V/N at 6-15N in z-axis	Piezoresistive	78
FFF	CNT/TPU	0-4N in x, y, and z-axis	2%-2.8%/N in x-axis 0.5%-0.7%/N in y-axis 0.6%-0.68%/N in z-axis*	Piezoresistive	68
Inkjet printing	PEDOT: PSS	0-0.16N	2.92%/N	Piezoresistive	74
DLP	Galinstan	0-10N	29%/N	Piezoresistive	58
Extrusion-based system	CNT/TangoPlus	0-10N	10%/N*	Piezoresistive	85
FFF	CNT/graphite nanosheet (GNP)-filled TPU	0-5N out of plane force	10%/N*	Piezoresistive	71
Inkjet printing	CNT/PDMS	0-0.5N	40%/N	Piezoresistive	72
Screen printing	Silver	0-0.04N	100%/N	Piezoresistive	86
Inkjet printing	Silver	0-8N	5.2 fF/N in normal and 13.1 fF/N in shear force	Capacitive	75
FFF	Conductive TPU	3.5-10N	0.01 pF/N*	Capacitive	65
FFF	Graphite/PDMS	0.004-0.0175N	0.2542 pF/mN	Capacitive	87
Aerosol-jet printing	Silver	0-9N	3.75 pF/N	Capacitive	57
Screen printing	Silver	1-100N	0.081% /N	Capacitive	82
FFF	Carbon based PLA	0-45N	0.088 %/N	Capacitive	69

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