1 # Supporting Information

2 # **Recent Advances in Carbohydrate Polymer-Supported**

3 # **Nanocomposites for Monitoring Breast Cancer Biomarkers:**

4 # **A Comprehensive Review**

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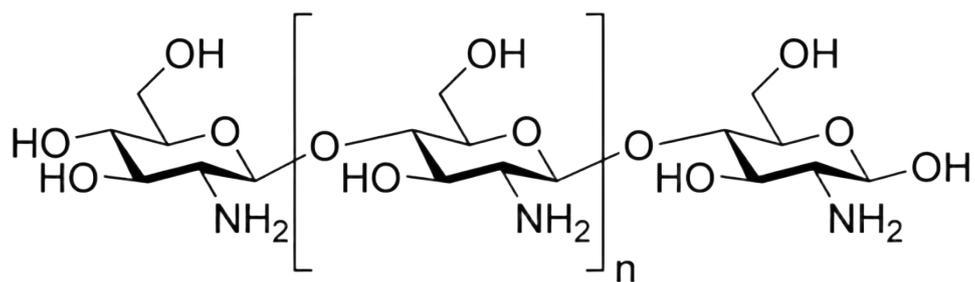
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25 * Corresponding author: Prof. Huijie Hou, E-mail: houhuijie@hust.edu.cn.
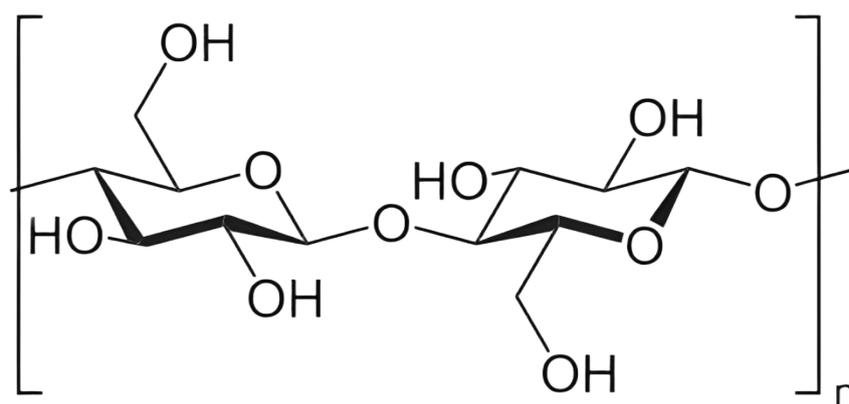
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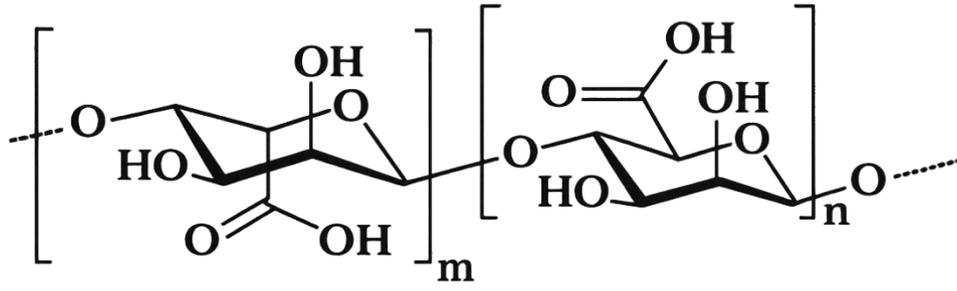27   **Fig. S1.** Chemical molecular structure formula of cellulose.

28

29   **Fig. S2.** Chemical molecular structure formula of chitosan.

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31 **Fig. S3.** Chemical molecular structure formula of alginate.

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33   **Fig. S4.** Chemical molecular structure formula of pectin.
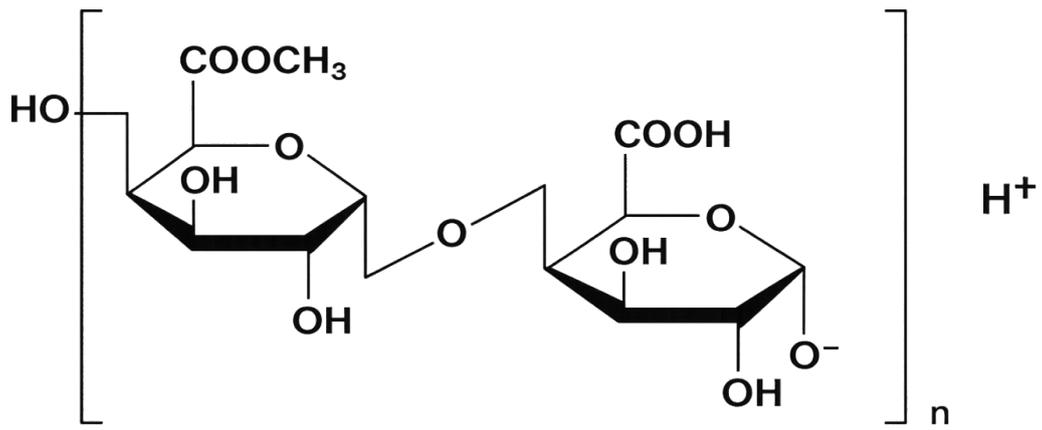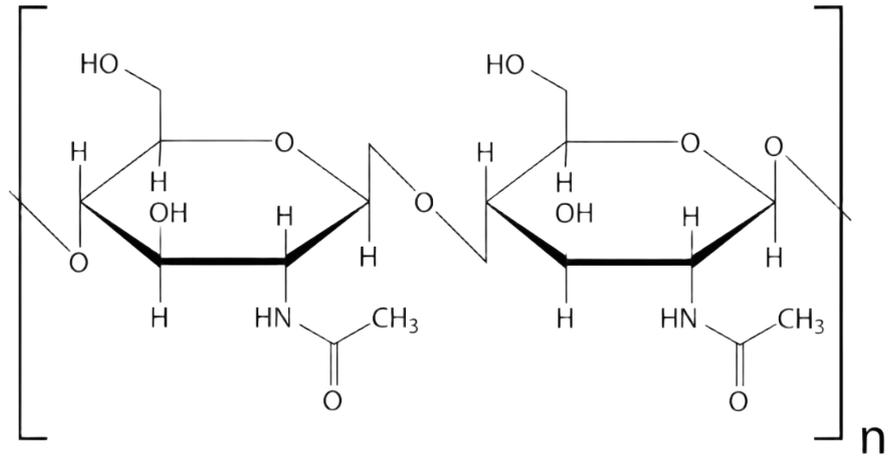
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35   **Fig. S5.** Chemical molecular structure formula of chitin
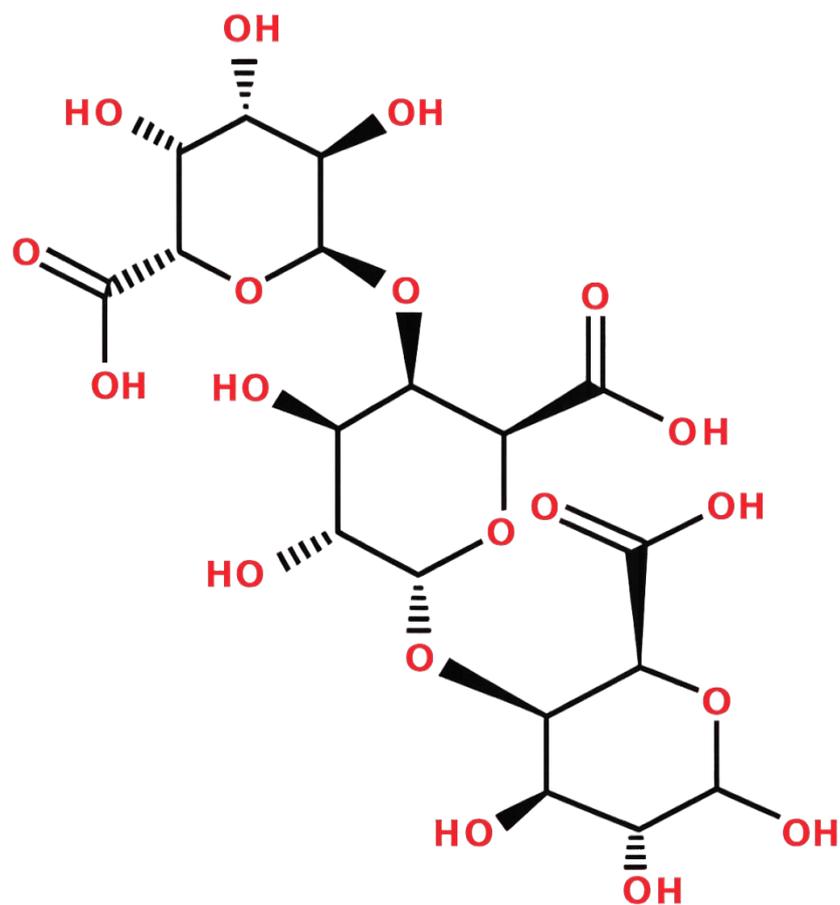
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37   **Fig. S6.** Chemical molecular structure formula of gelatin
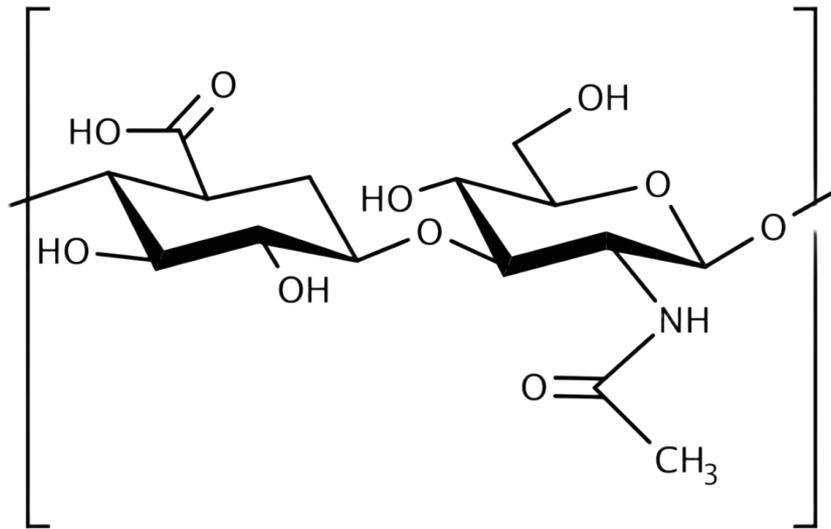
Fig. S7. Chemical molecular structure formula of hyaluronic acid.

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39
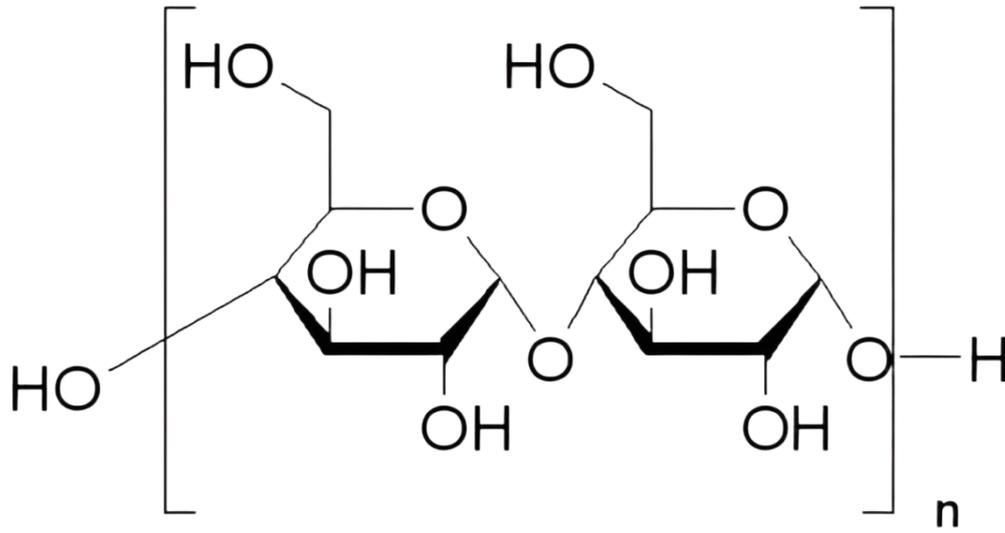
40

41   **Fig. S8.** Chemical molecular structure formula of starch.
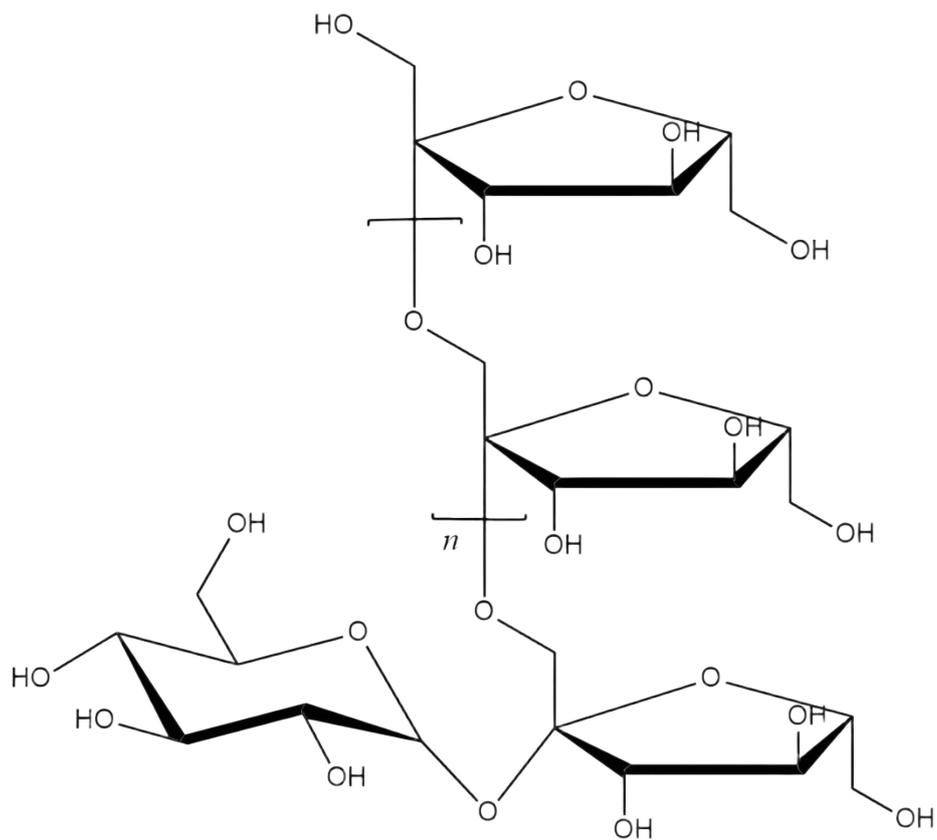
42

43   **Fig. S9.** Chemical molecular structure formula of inulin.
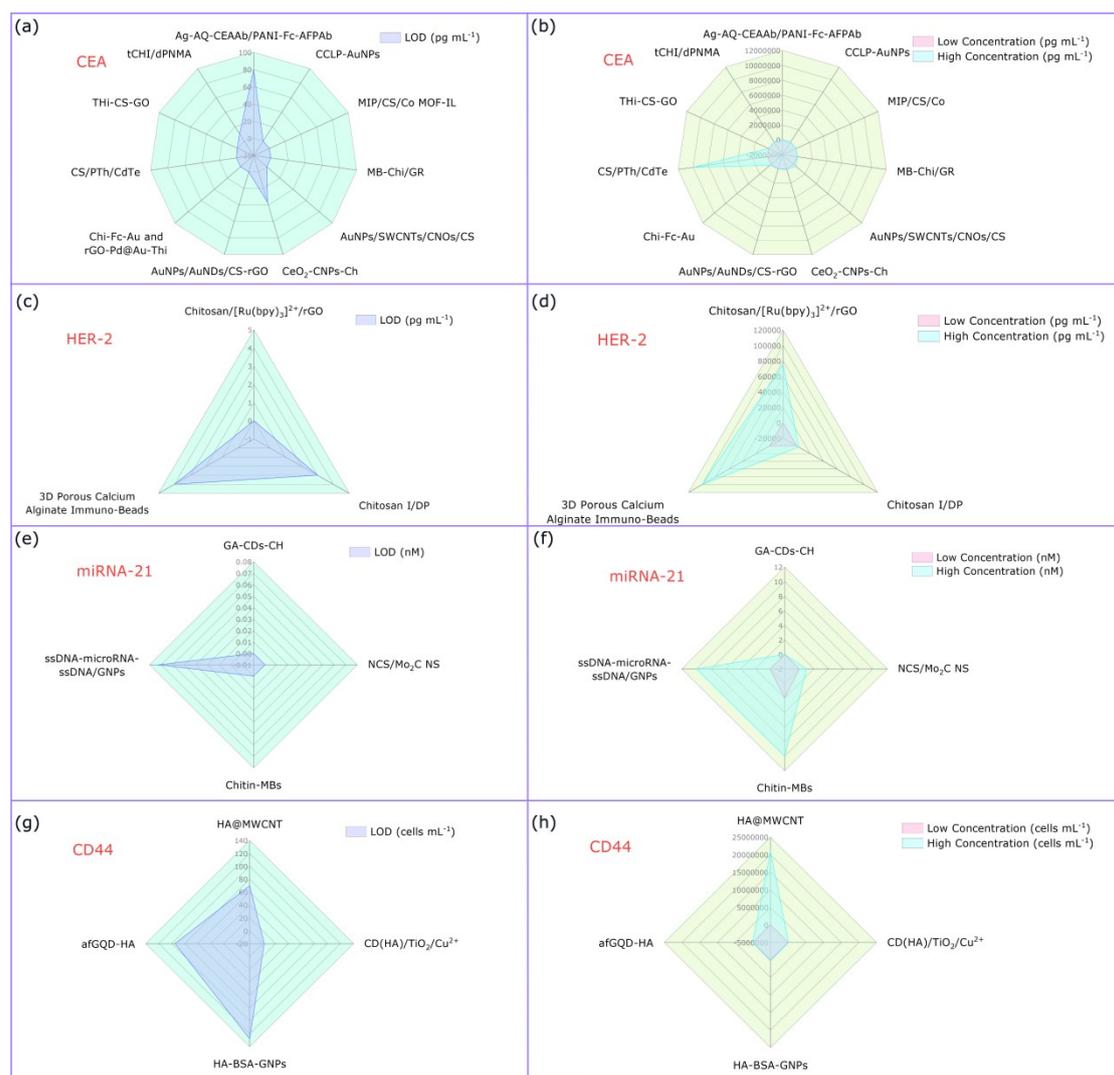
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45 **Fig. S10**. Comparative radar diagram of LOD and linear range for various CPs composites sensing

46 platforms in BC biomarker detection towards (a-b) CEA, (c-d) HER-2, (e-f) miRNA-21, and (g-h)

47 CD44.
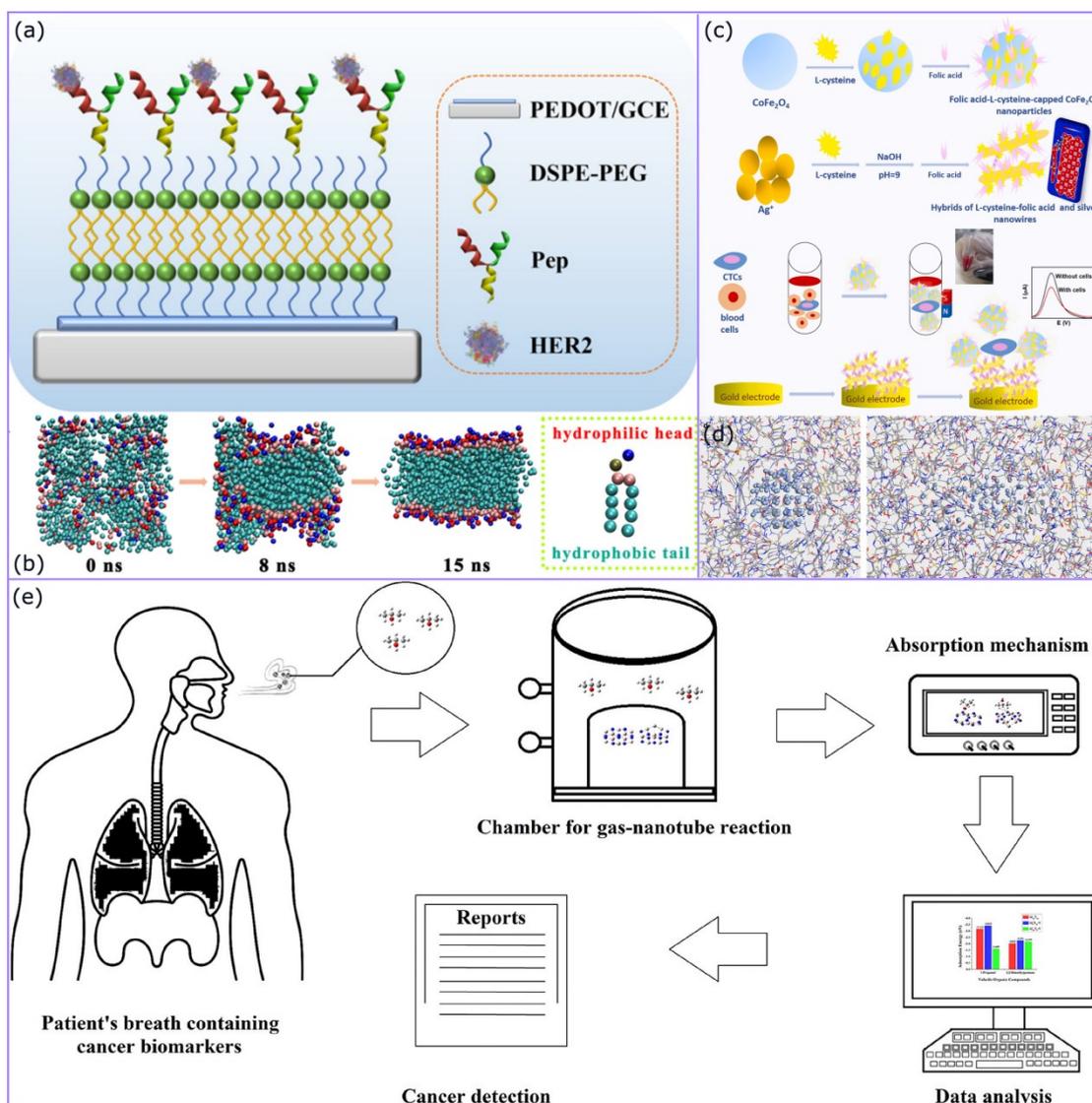
Fig. S11. (a) Schematic diagram for the fabrication of the HER-2 biosensor and (b) MD simulation snapshots of the DSPE at 0, 8, and 15 ns (The image on the right-hand side shows a schematic of a single DSPE molecule containing the hydrophilic head and hydrophobic tail). Copyright 2024, American Chemical Society. (c) Schematic display of the preparation of folic acid-L-cysteine-capped $CoFe_2O_4$ nanoparticles (CCF), hybrids of L-cysteine-folic acid and silver nanowires (FAgNWs), and magnetic cell separation and construction of an electrochemical nanocytosensor for the detection of MCF-7 cells. (d) Axial and side view of the final equilibrium configuration of FAgNWs in the MD simulation box. Copyright 2022, Elsevier. (e) Plausibility of V-doped aluminium nitride nanotubes for breast cancer detection. Copyright 2025, Elsevier.

Table S1. Common BC biomarkers with their characteristics, diagnosis, prognostic, and therapeutic applications

Biomarker Name	Size	Utility	Concentration Level in Biological Fluid	Ref.
CEA	150–200 kDa	Important for BC treatment strategy	3–5 ng mL^{-1} (2.5 μg L^{-1} in nonsmokers, 5 μg L^{-1} in smokers)	1–3
CA 125	200–2000 kDa	Prognostic for BC	< 35 U mL^{-1}	4,5
CA 15-3	300–450 kDa	Prognostic for BC	< 30 U mL^{-1}	6,7
CA 19-9	200–1000 kDa	Prognostic for BC	< 80 kU L^{-1}	8
CA 27.29	N/A	Prognostic for BC	< 25 U mL^{-1}	9
CA 72-4	220–400 kDa	Prognostic for BC	< 6.9 kU L^{-1}	10,11
CA 549	400–512 kDa	Prognostic for BC	< 10 kU L^{-1}	12,13
HER-2	185 kDa	Diagnostic and prognostic for BC	2–15 ng mL^{-1}	14,15
HER-3	180 kDa	Diagnostic only with HER2 for BC	60 pg mL^{-1}–2.55 ng mL^{-1}	16–18
BRCA1	220 kDa	Diagnostic for BC	N/A	19,20
BRCA2	390 kDa	Diagnostic for BC	N/A	19,20
CD44	85–95 kDa	Prognostic for BC	400–500 ng mL^{-1}	21–23
CD146	113 kDa	Prognostic for BC	~ 0.33 ± 0.09 ng mL^{-1}	24,25
CD105	180 kDa	Prognostic for BC	~ 25 U mL^{-1}	26,27
IL-6	21–28 kDa	Prognostic for BC	21–26 kDa	28,29
IL-8	8.4 kDa	Prognostic for BC	23 pg mL^{-1}	30,31
IL-10	18 kDa	Prognostic for BC	4.5–225.6 pg mL^{-1}	32,33
MMP-9	92 kDa	Prognostic for BC	N/A	34
MMP-1	52 kDa	Prognostic for BC	N/A	35
NCL	106 kDa	Prognostic for BC	N/A	36
VEGF	34–46 kDa	Prognostic for BC	< 291 pg mL^{-1}	37–39
TGF-β	25 kDa	Prognostic for BC	N/A	40

PD1	55 kDa	Prognostic for BC	N/A	41
COX-2	70–72 kDa	Prognostic for BC	N/A	42
ER-PR	N/A	Diagnostic and prognostic for BC	< 10 pg mL^{-1} and < 0.1 ng mL^{-1}	43
CTC	N/A	Prognostic and important in therapy monitoring of BC	0–1 CTC/7.5 mL	44–46
EpCAM	30–40 kDa	Diagnostic and prognostic for BC	N/A	47
Ferritin	450 kDa	Diagnostic and prognostic for BC	< 400 μg L^{-1}	48–50
uPA	52kDa	Prognostic for BC	5–10 μg L^{-1}	51,52
TN-C	180–250 kDa	Prognostic for BC	N/A	53
MDM2	90 kDa	Prognostic for BC	N/A	54
APE1	35.6 kDa	Prognostic for BC	N/A	55
MUC-1	120–225 kDa	Diagnostic and prognostic for BC	0.7–39.8 kU L^{-1}	56–58
EGFR (HER-1)	170–185 kDa	Diagnostic and prognostic for BC	1–25 ng mL^{-1}	59–61
AFP	65–70 kDa	Diagnostic and prognostic for BC	< 25 ng mL^{-1}	62,63
p53 Tumor Protein	53 kDa	Diagnostic and prognostic for BC	N/A	64
ISF miRNA	~22 nt	Diagnostic for BC	N/A	65,66
miRNA-16, mrRNA-21	20–24 nt	Diagnostic for BC	N/A	67–69
miRNA-27a	21–25 nt	Prognostic for BC	N/A	70,71
miRNA-148	21–22 nt	Prognostic for BC	N/A	72,73
miRNA-155	21–24 nt	Diagnostic for BC	N/A	74,75
miRNA-159c	19–25 nt	Prognostic for BC	N/A	76,77
miRNA-205, miRNA-210	19–25 nt	Diagnostic for BC	N/A	78–80
miRNA-222	18–25 nt	Prognostic for BC	N/A	81,82
MDA-MB-231 Cells	N/A	Immunotherapy for BC	N/A	83
MCF-10A Cells	N/A	BC proliferation signaling pathway	N/A	84

MCF-7 Cells	N/A	Targeted therapy for BC	N/A	85
SKBR-3 Cells	N/A	BC transformation control and microenvironment research	N/A	86
A549 Cells	N/A	BC metastasis target organ model	N/A	87
HeLa Cells	N/A	Mechanism comparison of BC types	N/A	88

59 **Note:** N/A, Not Applicable; BC, Breast Cancer; CEA, Carcinoembryonic Antigen; CA 125, Cancer Antigen 125; CA 15-3, Cancer Antigen 15-3; CA 19-9, Cancer Antigen 19-9; CA 27.29,

60 Cancer Antigen 27.29; CA 72-4, Cancer Antigen 72-4; CA 549, Cancer Antigen 549; HER-1, Human Epidermal Growth Factor Receptor 1; HER-2, Human Epidermal Growth Factor Receptor

61 2; HER-3, Human Epidermal Growth Factor Receptor 3; BRCA1, Breast Cancer Susceptibility Genes 1; BRCA2, Breast Cancer Susceptibility Genes 2; CD44, Cluster of Differentiation 44;

62 CD146, Cluster of Differentiation 146; CD105, Cluster of Differentiation 105; IL-6, Interleukin-6; IL-8, Interleukin-8; IL-10, Interleukin-10; MMP-9, Matrix Metallopeptidase-9; MMP-1, Matrix

63 Metallopeptidase-1; NCL, Nucleolin Protein; VEGF, Vascular Endothelial Growth Factor; TGF-β, Transforming Growth Factor-β; PD1, Programmed Death Receptor 1; COX-2, Cyclooxygenase-

64 2; ER-PR, Estrogen Receptor-Progesterone Receptor; CTC, Circulating Tumor Cell; EpCAM, Epithelial Cell Adhesion Molecule; uPA, Urokinase Plasminogen Activator; TN-C, Triple Negative

65 Breast Cancer; MDM2, Murine Double Minute 2; APE1, Apurinic/Apyrimidinic Endonuclease 1; MUC-1, Mucin-1; EGFR, Epidermal Growth Factor Receptor; AFP, Alpha-Fetoprotein; ISF

66 miRNA, Interstitial Fluid MicroRNA; miRNA, MicroRNA; MCF-10A Cells, Michigan Cancer Foundation-10A Cell Line; HeLa, Henrietta Lacks.

Table S2. Summary of cellulose, chitosan, hyaluronic acid, starch, and inulin-based composites modified biosensors for the detection of other cancer biomarkers

CPs	Disease	CPs-based Sensing Materials	Type of Sensors	Biomarker	Detection Method	Linear Range	LOD	LOQ	Sensitivity	Actual System	Ref.
Cellulose	Prostate Cancer	CNF/PAA Hydrogel	Colorimetric Sensor	Sar	Colorimetric Method	$0–1\times10^2$ μM	1×10 μM	Not Described	Not Described	Urine	89
		Cellulose/PVA/CMC-GO/NQS Hydrogel	Colorimetric Sensor	Sar	Colorimetric Method	$0–1\times10^2$ μM	25 μM	Not Described	Not Described	Urine	90
		Fe-GA MOF	FL Sensor	PSA	FL	$1\times10^{-1}–1.7\times10^2$ ng mL^{-1}	18×10^{-2} ng mL^{-1}	Not Described	Not Described	Serum	91
	Pancreatic Cancer	CA19-9MIP@CdTe QDs	FL Sensor	CA 19-9	FL	$2.76\times10^{-2}–5.23\times10^2$ U mL^{-1}	1.58×10^{-3} U mL^{-1}	Not Described	Not Described	Serum	92
	Colorectal Cancer	Ag NPs/CNC/GO Film	SERS Sensor	NBA	SERS Spectrum	$1\times10^{-4}–1\times10^{-8}$ M	3×10 nM	Not Described	Not Described	Serum	93
	Ovarian Cancer	Epoxy Cellulose Polymer-Embedded Tb-Acetylaceton	FL Sensor	CA 125	FL	$5\times10^{-1}–4.78\times10^2$ U mL^{-1}	9×10^{-2} U mL^{-1}	Not Described	Not Described	Serum	94

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						Linear Range	LOD		Sensitivity	Sample	Ref
Chitosan	Prostate Cancer	e PEDOT:PSS -MWCNT-CHIT	Electrochemical Sensor	Sar	CA	$0.89–123.846$ μM	1.1 nM	Not Described	3.02×10^6 μA mM^{-1}	Not Described	95
		CHIT/CuNPs/c-MWCNT	Electrochemical Sensor	Sar	CV	$1\times10^{-1}–1\times10^2$ μM	1×10^{-1} pM	Not Described	Not Described	Blood	96
		CS-PANI-MC	Electrochemical Sensor	Sar	CV	$1–1\times10^2$ μM	77×10^{-3} μM	Not Described	Not Described	Serum, Urine	97
		AuNPs/CHI	Electrochemical Sensor	PSA	DPV	$1–18$ ng mL^{-1}	1×10^{-3} ng mL^{-1}	Not Described	Not Described	Serum, Plasma, Urine	98
		TB/M-CeO$_2$/CMC/ILs	Electrochemical Sensor	PSA	CV	$5\times10^{-1}–5\times10$ ng mL^{-1}	16×10^{-2} pg mL^{-1}	Not Described	Not Described	Blood	99
		SO$_x$/MXene-Chi	Electrochemical Sensor	PSA	CV	$36–7.8\times10^3$ nM	18 nM	Not Described	Not Described	Not Described	100
		GF/CS-AuNPs	Electrochemical Sensor	PSA	DPV	$1\times10^{-3}–2\times10^2$ ng mL^{-1}	51×10^{-2} pg mL^{-1}	Not Described	Not Described	Serum	101
		CS-rGO	Electrochemical Sensor	PSA	DPV	$1–5$ ng mL^{-1}	8×10^{-1} pg mL^{-1}	Not Described	Not Described	Serum	102
		MoS$_2$QDs@g-C$_3$N$_4$@CS-AuNPs	Electrochemical Sensor	PSA	EIS	$1–2.5\times10^2$ pg mL^{-1}	71×10^{-2} pg mL^{-1}	Not Described	Not Described	Serum	103
		Chitosan-	Electrochemical	BSA	SWV	1 fg mL^{-1}–	1 fg mL^{-1}	Not	Not	Serum	104

	Pb$_2$[Fe(CN)$_6$]-PDDA-GO	cal Sensor				1×10^2 ng mL^{-1}		Described	Described		
	N-rGO@CMWCNTs/CS@AuNPs	Electrochemical Sensor	CA 125	DPV	1×10^{-1} pg mL^{-1}–1×10^2 ng mL^{-1}	4×10^{-2} pg mL^{-1}	Not Described	Not Described	Serum	105
	CHIT-NRGO	Electrochemical Sensor	miRNA-660	EIS	5–2×10 µg mL^{-1}	1.72 µg mL^{-1}	Not Described	Not Described	Serum	106
	Ti$_3$C$_2$T$_x$@CS	Electrochemical Sensor	CYFRA21-1	DPV	2–2×10 ng mL^{-1}	1.7 ng mL^{-1}	Not Described	Not Described	Serum	107
Lung Cancer	AuNPs/Thi/MWCNT-NH$_2$	Electrochemical Sensor	CYFRA21-1	DPV	1×10^{-1}–1.5×10^2 ng mL^{-1}	43 pg mL^{-1}	Not Described	Not Described	Serum	108
	NBA/AuNPs/AAR, THI/AuNPs/AAR	SERS Sensor	CEA, CK-19	SERS Spectrums	5×10^{-2}–8×10 ng mL^{-1}	1×10^{-2} ng mL^{-1}, 0.4×10^{-2} ng mL^{-1}	Not Described	Not Described	Serum	109
	GO-CS/PVP-AuNUs	Electrochemical Sensor	miRNA-141, miRNA-21	SWV	2–1×10^5 fM, 24×10^{-2} fM	89×10^{-2} fM	Not Described	Not Described	Blood	110
	CoB NS	FL Sensor	ctDNA	FL	2 × 10^2–1.5 × 10^3 pM	79.88 pM	Not Described	Not Described	Mouse	111
	CS/MoS$_2$	Electrochemical Sensor	NSE	CV	1×10^{-1}–1×10^2 ng mL^{-1}	Not Described	Not Described	3.35 µA (ng·mL·cm^2)$^{-1}$	Not Described	112
	Zeolite-	Colorimetric	ProGRP	Colorimetric	0–1.05×10^2	75 pg mL^{-1}	Not	Not	Serum	113

		Chitosan-TiO$_2$ Microspheres-Se NPs	Sensor		Method	pg mL^{-1}		Described	Described		
	Pancreatic cancer	Cu-CP, Cd-CP, Pb-CP, Zn-CP	Electrochemical Sensor	CEA, CA 19-9, CA 125, CA 242	SWV	1×10^{-1}–1×10^2 ng mL^{-1}, 1–1.5×10^2 ng mL^{-1}, 1–1.5×10^2 ng mL^{-1}, 1–1.5×10^2 ng mL^{-1}	0.02 U mL^{-1}, 0.4 U mL^{-1}, 0.3 U mL^{-1}, 0.4 U mL^{-1}	Not Described	Not Described	Serum	114
	Stomach Cancer	Graphene-Sulfur-TT	Electrochemical Sensor	CA19-9	CC	2.1 × 10^{-13}–5 × 10^2 U mL^{-1}	2.1 × 10^{-13} U mL^{-1}	Not Described	8.18 × 10^9 mL (s·μg)$^{-1}$	Blood, Urine, Saliva, Tissue	115
	Colorectal Cancer	THi-CS-GO	Electrochemical Sensor	CEA	DPV	1 × 10^{-2}–8× 10 ng mL^{-1}	23× 10^{-4} ng mL^{-1}	Not Described	Not Described	Serum	116
	Thyroid Cancer	Eu: Cs dot	ECL Sensor	BRAF V600E	ECL Spectrum	1 fM–1× 10^2 nM	0.5 fM	Not Described	Not Described	Hyroid Cancer Exosome	117
Alginate	Liver Cancer	3,3′-bis-(dimethyl [6,6']bi[benz	FL Sensor	AFP	FL	1–2.5× 10^2 ng mL^{-1}	1× 10^{-1} ng mL^{-1}	1.6 ng mL^{-1}	Not Described	Serum	118

	Cancer Type	Material	Sensor Type	Target	Method	Linear Range	LOD			Sample	Ref
Hyaluronic Acid	Lung Cancer	o[b]phenoxazinyl]-3,3′-ylidene) ammonium chloride 4 MNPs-SSMCC/PNA/tDNA/Zr^{4+}/HA-TBA/BMP-NHS/FA	FL Sensor	CYFRA21-1	FL	1×10^{-6}–1×10^{-10} M	7.8×10^{-17} M	Not Described	Not Described	Serum	119
	Colon Cancer, Prostate Cancer, Bladder Cancer, lung Cancer	HA-FITC@AuNPs Hydrogel	FL Sensor	HAse	FL	5×10^{-1}–1×10^{2} U mL^{-1}	14×10^{-2} U mL^{-1}	Not Described	Not Described	A549 Cells	120
Starch	Head and Neck Cancer	ST-BA	FL Sensor	sAA	FL	Not Described	Not Described	Not Described	Not Described	Blood	121
	Prostate Cancer	KI-Starch	Colorimetric Sensor	PSA	Colorimetric Method	1 pg/mL–1 µg mL^{-1}	0.46 pg mL^{-1}	Not Described	Not Described	Serum	122
Inulin	Gastrointestinal Cancer	Inulin-IQ/Ag-TiO$_2$/Reduced Graphene	Electrochemical Sensor	CEA	DPV	2.05×10^{-8}–5.12×10^{-7} µg mL^{-1}	2.05×10^{-8}–5.12×10^{-7} µg mL^{-1}	Not Described	9.4×10^{4} mol $(t_{on}\cdot L)^{-1}$	Blood	123

	Oxide

68 **Note:** CPs, Carbohydrate Polymers; LOD, Limit of Detection; LOQ, Limit of Quantitation; Ref., Reference; CNF/PAA Hydrogel, Cellulose Nanofibers/Polyacrylic Acid Hydrogel; Sar, Sarcosine;

69 Cellulose/PVA/CMC-GO/NQS Hydrogel, Cellulose/Polyvinyl Alcohol/Sodium Carboxymethyl Cellulose-Graphene Oxide/1,2-Naphthoquinone-4-Sulphonic Acid Sodium Salt; Fe-GA MOF,

70 Fe(III)-Gallic Acid Metal Organic Framework; FL, Fluorescence; PSA, Prostate-Specific Antigen; MIP@CdTe QDs, Molecularly Imprinted Polymers@Cadmium Telluride Quantum Dots; CA

71 19-9, Cancer Antigen 19-9; FL, Fluorescence; Ag NPs/CNC/GO Film, Silver Nanoparticle/Cellulose Nanocrystal/Graphene Oxide Film; SERS, Surface-Enhanced Raman Scattering; NBA, Nile

72 Blue A; CA 12-5, Cancer Antigen 12-5; PEDOT:PSS-MWCNT-CHIT, Poly (3,4-Ethylenedioxythioph-Ene):Poly (Styrene Sulfonate)-Multiwalled Carbon Nanotube-Chitosan; CHIT/CuNPs/c-

73 MWCNT, Chitosan/Copper Nanoparticles/Carboxylated Multi-Walled Carbon Nanotubes; CV, Cyclic Voltammetry; CS-PANI-MC, Chitosan-Polyaniline-Mesoporous Carbon; AuNPs/CHI,

74 Chitosan/Gold Nanoparticles; DPV, Differential Pulse Voltammetry; TB/M-CeO$_2$/CMC/ILs, Toluidine Blue/Mesoporous-Cerium Oxide/Carboxymethyl Chitosan/Ionic Liquids; SO$_x$/MXene-Chi,

75 Sarcosine Oxidase/MXene-Chitosan; GF/CS-Au NPs, Graphene Fiber Film/Chitosan-Gold Nanoparticles; CS-rGO, Chitosan-Reduced Graphene Oxide; MoS$_2$QDs@g-C$_3$N$_4$@CS-AuNPs,

76 Molybdenum Disulfide Quantum Dots@Graphitic Carbon Nitride@Chitosan-Gold Nanoparticles; Chitosan-Pb$_2$[Fe(CN)$_6$]-PDDA-GO, Chitosan-Pb$_2$[Fe(CN)$_6$]-Poly(diallyldimethylammonium

77 chloride)-Graphene Oxide; BSA, Bovine Serum Albumin; SWV, Square Wave Voltammetry; N-rGO@CMWCNTs/CS@AuNPs, Nitrogen-Doped Reduced Graphene Oxide@Carboxylated Multi-

78 walled Carbon Nanotubes/Chitosan@Gold Nanoparticles; CA 125, Cancer Antigen 125; CHIT-NRGO, Chitosan-Nitrogen Doped Reduced Graphene Oxide; miRNA, MicroRNA; EIS,

79 Electrochemical Impedance Spectroscopy; Ti$_3$C$_2$T$_x$@CS, Ti$_3$C$_2$T$_x$@Chitosan; CYFRA21-1, Cytokeratin 19 Fragment 21-1; AuNPs/Thi/MWCNT-NH$_2$, Gold Nanoparticles/Thionine/Amino-

80 Functionalized Carbon Nanotube; NBA/AuNPs/AAR, Nile Blue A/Gold Nanoparticles/Aminosalicylic Acid-Based Resin; THI/AuNPs/AAR, Thionine/Gold Nanoparticles/Aminosalicylic Acid-

81 Based Resin; SERS, Surface Enhancement of Raman Scattering; CEA, Carcinoembryonic Antigen; CK-19, Cytokeratin-19; GO-CS/PVP-AuNUs, Graphene Oxide-

82 Chitosan/Polyvinylpyrrolidone-Gold Nanourchin; CoB NS, Cobalt Boride Nanosheet; ctDNA, Circulating Tumor DNA; CS/MoS$_2$, Chitosan/Molybdenum Disulfide; NSE, Neuron-Specific

83 Enolase; ProGRP, Progastrin-Releasing Peptide; CA 125, Cancer Antigen 125; CA 242, Cancer Antigen 242; CC, Chronocoulometry; Cu-CP, Cu^{2+}-doped Chitosan-Poly(Acrylic Acid)

84 Nanospheres; Cd-CP, Cd^{2+}-doped Chitosan-Poly(Acrylic Acid) Nanospheres; Pb-CP, Pb^{2+}-doped Chitosan-Poly(Acrylic Acid) Nanospheres; Zn-CP, Zn^{2+}-doped Chitosan-Poly(Acrylic Acid)

85 Nanospheres; THi-CS-GO, Thionine-Chitosan-Graphene Oxide; Eu: Cs dot, Eu-Doped Chitosan Carbon Dot; ECL, Electrochemiluminescence; AFP, Alpha-Fetoprotein; MNPs-

86 SSMCC/PNA/tDNA/Zr^{4+}/HA-TBA/BMP-NHS/FA, Magnetic Nanoparticles-Cyclohexane-1-Carboxylic Acid 3-Sulfo-N-Hydroxysuccinimide Ester Sodium Salt/Peptide Nucleic Acid/Target

87 DNA/Zr^{4+}/Hyaluronic Acid-Tetrabutylammonium Hydroxide/2-Bromo-2-Methylpropionic Acid-N-Hydroxysuccinimide/Fluorescein o-Acrylate; HA-FITC@AuNPs Hydrogel, Hyaluronic Acid-

88 Fluorescein Isothiocyanate@Gold Nanoparticles Hydrogel; HAse, Hyaluronidase; ST-BA, Barbituric Acid-Starch; sAA, Salivary Alpha-Amylase; KI Starch, Potassium Iodide Starch; AuNP@Fc-

89 Lac, Gold Nanoparticles@Ferrocene Conjugates-Lactose.

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