Supplementary Information (SI) for Nanoscale.

Quantum Dot-Infused Nanocomposites: Revolutionizing Diagnostic Sensitivity

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Supplementary Material

Supplementary Table 1. Summary of Key Studies on Quantum Dot-Infused Nanocomposites for Ultra-Sensitive Diagnostics

Quantum Dot Type	**Nanocomposite Material**	**Diagnostic Application**	**Sample Type**	**Detection Method**	**Limit of Detection (LOD)**	**Sensitivity Achieved**	**Key Findings**	**Ref.**
CdSe/ZnS QDs	Protein-Conjugated Nanocomposite	Enzyme Activity Detection	In Vitro (buffer solution)	FRET-Based Fluorescence	10 nM	Nanomolar (nM) levels	Demonstrated QD-based FRET for detecting enzyme activities	1
CdSe/ZnS QDs	PEGylated Nanocomposite	Tumor Imaging	In Vivo (mouse models)	Near-Infrared Fluorescence Imaging	Not specified (High specificity)	High specificity	Developed QD nanocomposites for targeted in vivo tumor imaging	2
CdTe QDs	Au Nanoparticle Composite	DNA Detection	In Vitro (synthetic samples)	Electrochemical Sensing	0.5 fM	Femtomolar (fM) levels	Achieved ultra-sensitive DNA detection using QD-Au nanocomposites	3
CdSe/ZnS QDs	Graphene Oxide Composite	MicroRNA Detection	Serum Samples	Fluorescence Quenching	10 pM	Picomolar (pM) levels	Developed QD-GO nanocomposite for sensitive microRNA detection	4
Carbon QDs	Polymer Nanocomposite	Glucose Sensing	Blood Samples	Fluorescence Sensing	2 µM	Micromolar (µM) levels	Created biocompatible carbon QD nanocomposites for glucose sensing	5
CdSe/ZnS QDs	Magnetic Nanoparticle Composite	Bacteria Detection	Water Samples	Magnetofluorescent Imaging	Detection in 30 min	Rapid detection	Combined magnetic separation and fluorescence for bacterial detection	6
PbS QDs	Silica Nanocomposite	Deep Tissue Imaging	In Vivo (mouse models)	Near-Infrared II Imaging	Not specified (Enhanced depth)	Enhanced imaging depth	Developed NIR-II QD nanocomposites for deep tissue imaging	7
Perovskite QDs	Polymer Matrix Nanocomposite	Heavy Metal Ion Detection	Environmental Samples	Fluorescence Quenching	0.1 nM	Nanomolar (nM) levels	Used perovskite QD nanocomposites for sensitive metal ion detection	8
CdSeTe QDs	Hydrogel Nanocomposite	Wound Healing	In Vivo (animal	Fluorescence Imaging	Real-time monitoring	Real-time monitoring	Developed QD-infused hydrogels for monitoring	9

		Monitoring	models)				wound healing processes	
Carbon QDs	MOF Nanocomposite	Cancer Biomarker Detection	Serum Samples	Electrochemiluminescence	0.3 fM	Femtomolar (fM) levels	Created CQD-MOF composites for ultra-sensitive detection of cancer biomarkers	10
CdSe/ZnS QDs	DNA-Au Nanocomposite	Pathogen Detection	Clinical Samples	FRET-Based Fluorescence	50 aM	Attomolar (aM) levels	Developed a QD-DNA-Au nanocomposite for ultra-sensitive pathogen detection	11
InP QDs	Silica-Coated Nanocomposite	Live Cell Imaging	Cell Cultures	Confocal Fluorescence Microscopy	Not specified (High resolution)	High resolution	Synthesized biocompatible InP QD nanocomposites for long-term live cell imaging	12
Carbon QDs	MOF Nanocomposite	Antibiotic Detection	Water Samples	Fluorescence Sensing	5 nM	Nanomolar (nM) levels	Developed CQD-MOF composites for sensitive detection of antibiotics in water samples	13
CdS QDs	Polymer Nanocomposite	Neurotransmitter Detection	Cerebrospinal Fluid Samples	Electrochemical Sensing	0.1 pM	Picomolar (pM) levels	Achieved highly sensitive detection of neurotransmitters using QD-polymer nanocomposites	14
Perovskite QDs	Graphene Nanocomposite	Viral RNA Detection	Clinical Samples	Photoluminescence Sensing	0.2 fM	Femtomolar (fM) levels	Developed perovskite QD-graphene nanocomposites for ultra-sensitive detection of viral RNA	15
Carbon Nitride QDs (CNQDs)	CNQDs/Polyaniline (PANI)	Non-invasive glucose monitoring	Biological samples	Electrochemical assay	0.1 µM	High		16

Graphene QDs (GQDs)	GQDs with Au5Ir nanoparticles	Atrazine detection in environmental water	Environmental water samples	Electrochemical biosensor	0.02 nM	Very High	Au5Ir@GQDs nanocomposite combined with DNA walker enabled highly sensitive and selective atrazine detection.	17

Overview of key works on quantum dot-infused nanocomposites for ultra-sensitive diagnostics, including types, applications, and detection methods.

Supplementary Table 2. Comparative Analysis of Quantum Dot Materials for Ultra-Sensitive Diagnostic Applications.

Quantum Dot Material	Core Composition	Shell Composition	Emission Wavelength Range (nm)	Quantum Yield (%)	Surface Functionalization	Biocompatibility	Stability	Diagnostic Application	Ref.

CdSe/ZnS QDs	CdSe	ZnS	450–650	Up to 80%	PEGylation	Moderate	High	Cancer Imaging	2
InP/ZnS QDs	InP	ZnS	500–700	Up to 60%	Carboxyl Groups	Good	Moderate	Cellular Imaging	18
Carbon QDs	Carbon	None	350–550	Up to 30%	Amino Groups	Excellent	High	Glucose Sensing	5
PbS QDs	PbS	None	1000–1400	Up to 50%	Thiol Groups	Low	Moderate	Deep Tissue Imaging	19
Perovskite $CsPbBr_3$ QDs	$CsPbBr_3$	None	450–550	Up to 90%	Ligand Exchange	Poor	Low	Metal Ion Detection	20
Silicon QDs	Silicon	None	400–700	Up to 20%	Hydroxyl Groups	Excellent	High	Biosensing	21
CdTe QDs	CdTe	None	550–750	Up to 70%	Mercaptoacetic Acid	Moderate	Moderate	DNA Detection	22
ZnO QDs	ZnO	None	350–400	Up to 40%	Silanization	Good	High	Pathogen Detection	23
$CuInS_2$ QDs	$CuInS_2$	ZnS	550–800	Up to 50%	Polymer Coating	Good	Moderate	Fluorescence Imaging	24
CdSeTe QDs	CdSeTe	ZnS	650–800	Up to 85%	Hydrogel Embedding	Moderate	High	Wound Healing Monitoring	25
Graphene Quantum Dots	Graphene	None	400–600	Up to 25%	Nitrogen Doping	Excellent	High	Neurotransmitter Detection	26
Mn-Doped ZnS QDs	ZnS	None	580	Up to 50%	Silica Coating	Good	High	Multiplexed Detection	27
Ag_2S QDs	Ag_2S	None	900–1300	Up to 15%	PEGylation	Good	Moderate	NIR-II Imaging	28
Cd-free InAs QDs	InAs	ZnSe	800–1000	Up to 40%	Phospholipid Coating	Moderate	Moderate	In Vivo Imaging	29
ZnSe QDs	ZnSe	ZnS	450–550	Up to 30%	Carboxyl Groups	Good	High	Biosensing	30
Au Nanocluster QDs	Gold	None	600–800	Up to 10%	BSA Conjugation	Excellent	High	Cancer Biomarker Detection	31
CdS QDs	CdS	ZnS	500–600	Up to 65%	Polymer Encapsulation	Moderate	Moderate	Environmental Sensing	26

Nitrogen-Doped Carbon QDs	Carbon	None	450–550	Up to 35%	Amino Groups	Excellent	High	Antibiotic Detection	[32]
MoS_2 Quantum Dots	MoS_2	None	400–500	Up to 20%	PEGylation	Good	Moderate	Biosensing	[33]
Cd-Free ZnTe QDs	ZnTe	ZnS	450–550	Up to 25%	Thiol Groups	Good	Moderate	Cellular Imaging	[34]
CdSeZnS/ZnS QDs	CdSeZnS	ZnS	500-650	Up to 98%	Polymer Coating	Excellent	High	cellular Imaging, Cancer Detection	[35]
CdSe/ZnS QDs	CdSe	ZnS	600-650	Up to 75%	Carboxylation	Good	High	Detection of CP4-EPSPS protein in genetically modified crops	[36]

Comparative studies of different quantum dot materials are presented, underlining their core-shell composition, emission wavelength, functionalization, biocompatibility, stability, and application in diagnostics. The qualitative terms ‘high’, ‘moderate’, and ‘low’ for biocompatibility and stability are based on reported experimental data, including cytotoxicity, immune response, and degradation behavior. ‘High biocompatibility’ indicates low toxicity and good biological interaction, while ‘low’ implies adverse effects. Similarly, ‘high stability’ refers to good resistance to degradation and aggregation. These labels are used for comparative purposes only, not as quantitative metrics.

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CNQDs/PANI nanocomposite exhibited outstanding electrochemical performance, suitable for non-invasive glucose monitoring.