Quantum Dot-based Fluorescent Sensing

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Quantum dots (QDs) have been developed for sensing applications, such as biosensing and bioimaging, owing to their excellent fluorescence properties and advantages over traditional organic dyes, such as high stability, facile surface modification for target analytes, and size-controlled optoelectronic properties (Fig. 1). Traditionally, semiconductor QDs have been applied for QD-based sensing, where compounds like CdS, CdSe, CdTe, CdS@ZnS, CdSe@ZnS are typically used. Representative recent progress is, for example, that Kumar et al. developed photoluminescence quenching based detection of Cu\textsuperscript{2+} in aqueous medium by CdS QDs with a surface modification of thiourea, describing Cu\textsuperscript{2+} sensing in drinking and ground water.\textsuperscript{3} Representative recent progress is, for example, that Kumar et al. developed photoluminescence quenching based detection of Cu\textsuperscript{2+} in aqueous medium by CdS QDs with a surface modification of thiourea, describing Cu\textsuperscript{2+} sensing in drinking and ground water. Lu et al. reported on the selective and sensitive detection of silver(I) ion CdTe QDs capped with glutathione and thioglycolic acid. Based on the specific interaction between Ag\textsuperscript{+} and cysteine bases, a label-free DNA sensor for the detection of Ag\textsuperscript{+} in aqueous solution was developed using the CdTe QDs. Guan et al. reported a new method for the detection of trace Hg\textsuperscript{2+} in water based on the fluorescence quenching of thiol-functionalized poly(vinyl alcohol) capped CdS QDs.\textsuperscript{3} The fluorescence intensity increased linearly with the Hg\textsuperscript{2+} concentration over the range of 2 to 4000 nM, with a detection limit of 1 nM. Moreover, the system was resistant to interference from a number of co-existing metal ions, promising development for the detection of Hg\textsuperscript{2+} in environmental samples.

The utilization of fluorescence resonance energy transfer is attractive in QD-based fluorescent sensing, where the QDs act as the donor chromophore. Haghieh et al. reported a separation-free ligase detection reaction assay based on fluorescence resonance energy transfer from a donor quantum dot to an acceptor fluorescent dye. This assay could successfully detect one cancer mutation among 10 wild-type templates. The mutation-discrimination threshold was improved by one order of magnitude by replacing the original acceptor dye (Alexa Fluor 647) with another fluorescent dye (Cyanine 5). Pillai et al. investigated the steady state and time-resolved photoluminescence quenching of streptavidin modified CdSe/ZnS QDs instigated by biotin-peptide-BHQ-1 (biotin-pep-BHQ-1) molecule.\textsuperscript{4} They found that the self-assembled QDs-(pep-BHQ)\textsubscript{n} conjugates could detect matrix metalloproteinases-2 (MMP-2) produced by cancer cells at a detection limit of 1 ng/mL. QDs have also been recognized as being a promising fluorescent probe for bioimaging. Oghihara et al. investigated the transduction function of a cationic dextran hydroxypropyl-trimethyl ammonium chloride-coated magnetic iron oxide nanoparticle (TMADM-03) for transducing quantum dots (QDs) into adipose tissue-derived stem cells (ASCs).\textsuperscript{5} The fluorescence intensity of ASCs labeled with QDs using TMADM-03 was much higher than that of QDs-only labeling.

In cadmium-based QDs, released cadmium ions become problematic because of their cellular toxicity. More recently, cadmium-free quantum dots were introduced, such as carbon dots, graphene QDs, silicon QDs, and gold nanoclusters, in an effort to produce more biocompatible QDs. Oskoei et al. reported on the selective determination of trinitrotoluene (TNT) based on energy transfer between carbon dots and gold nanoparticles.\textsuperscript{6} Compared to previous methods, this method has advantages of relatively high sensitivity, low cost, easier operation and requires a short analysis time. Gong et al. also developed an energy transfer-based biosensor using nitrogen-doped carbon dots and gold nanoparticles for the highly sensitive detection of organophosphorus pesticides.\textsuperscript{7} Glutathione is an important antioxidant in body fluids and tissues, which inhibit damage to essential cellular constituents caused by reactive oxygen species. Sivasankaran et al. reported on the fluorescence determination of glutathione using tissue paper-derived carbon dots as fluorophores with a detection limit of 1.74 nM.\textsuperscript{8} The developed sensor was also successfully used for the determination of glutathione in artificial saliva samples. In the past decades, protein stabilized fluorescent gold nanoclusters have been drawing intense research interest because of their excellent photo stability and potential sensing applications. Li et al. reported on chicken-egg white-stabilized gold nanoclusters for the selective and sensitive detection of Hg(II) with a limit of detection of 0.51 \textmu M in the presence of equivalent copper ions.\textsuperscript{9}

QD-based fluorescence sensing utilizes the interaction of the analyte with the QDs. This interaction can be controlled by changing the organic ligands on the surface of the QD. Hence, QDs are promising candidates for the fluorescent sensing of a variety of analytes, including toxic metals and biological molecules. Further innovation in QD-based fluorescence sensing is expected to continue through improvements of the synthetic methods for QDs and their surface modifications.

**Keywords** Quantum dots-based sensing, fluorescent probes, biosensing, bioimaging

Fig. 1 Schematic image of quantum dot-based fluorescent sensing for target analytes.

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Highlights

- Quantum Dot-based Fluorescent Sensing
- Quantum dots (QDs) have been developed for sensing applications, such as biosensing and bioimaging, owing to their excellent fluorescence properties and advantages over traditional organic dyes.
- Representative recent progress includes detection of Cu\textsuperscript{2+}, Hg\textsuperscript{2+}, Ag\textsuperscript{+}, and other analytes.
- Fluorescence resonance energy transfer is a key method for selective detection.
- Quantum dots offer unique advantages over traditional organic dyes, including stable fluorescence and size-controlled properties.
- Future research includes improving sensitivity, lowering costs, and enhancing biocompatibility for clinical applications.
References