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ELECTRONIC SUPPLEMENTARY INFORMATION (ESI)

High quantum-yield luminescent MoS_2 quantum dots with variable light emission created via direct ultrasonic exfoliation of MoS_2 nanosheets

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Experimental section

Synthesis of MoS_2 quantum dots

The synthesis procedure of MoS_2 quantum dots (QDs) was modified on the basis of synthesis of 2D MoS_2 nanosheets[1] via ultrasonic method. 0.4 gram of MoS_2 powders was added into 20 mL of NMP, forming a black solution used for ultrasonication. The process of exfoliating MoS_2 powder was conducted for three hours using ultrasonic processor KQ-3200 with frequency of 40 kHz (150 W, Kun Shan Ultrasonic Instrument Co., Ltd, China). Ices were added into the processor in case of excessive heat in the process. Then 0.05 M sodium hydroxide (NaOH), 0.05 M sodium chloride (NaCl) and 0.025 M sodium carbonate (Na_2CO_3), 0.05 M lithium hydroxide (LiOH) were added into four solutions respectively followed by ultrasonication for another two hours. The solution without any additives was also sonicated during the one hour for comparison. Finally, the solution was centrifuged at the speed of 7000 rpm for 30 min after several hours' standing respectively. The resulting solution was filtered several times through a 0.22 μm microporous membrane whose filter head is of organic phase. After this process, the solution with MoS_2 QDs was obtained.

Characterization

The obtained stable solutions were decanted and characterized using various experimental tools. Transmission electron microscopy (TEM), high resolution TEM (HRTEM) and selected area electron diffraction (SAED) measurements were performed by using a JEM-2100 microscope. The samples for TEM characterization were prepared by drop casting the diluted MoS_2 solution onto the carbon-coated copper grid, followed by evaporating the solvent in air under the luminescence of the lamp overnight.

Absorption spectra were obtained using a UV-3600 spectrometer. The RF-5301PC fluorospectrophotometer was used to study the steady-state luminescence properties, with slit size of 5 nm. In order to further study the transient state of QD optical properties, fluorescence lifetime and quantum yield were measured by

Fluorolog 3 spectrometer ((Horiba Jobin Yvon). The absolute quantum yield for photoluminescence is defined as the ratio of the number of emitted photons to the number of absorbed photons. Finally the confocal fluorescence microscope (Leica TCS SP8) was employed to measure the fluorescence images of MoS_2 QDs under three excitation wavelengths: 405 nm, 488 nm and 552 nm.

Bio-imaging

To apply the MoS_2 QDs to bio-imaging, Lung cells were cultured on cover slides for 24 h at 37 ℃ before imaging. Then an aliquot of diluted MoS_2 QDs suspension was added to the well of a chamber slide containing the cells cultured for 24 h. The chamber slide was then incubated at 37℃ in a CO_2 incubator for 30 minutes for MoS_2 QDs uptake. Then excess MoS_2 QDs were removed by washing 3-5 times with phosphate buffer solution before fixation of cells on the slide for inspection with the confocal fluorescence microscope. The bacteria were performed using a similar method.

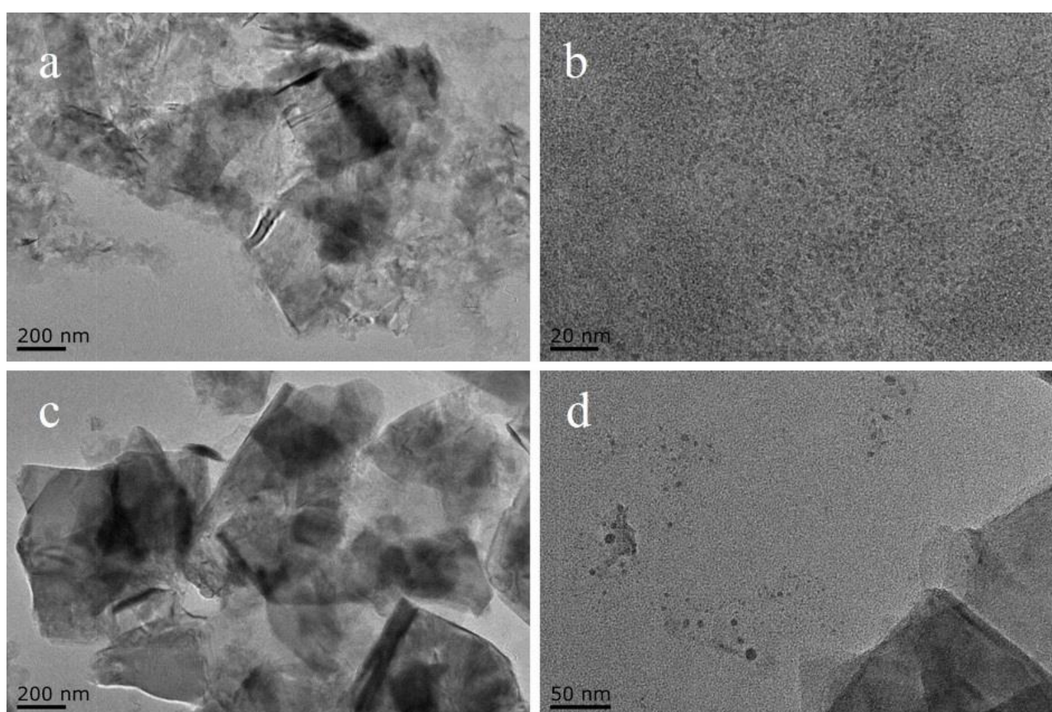

Fig.S1 (a), (b) TEM images of MoS_2 nanosheets and QDs prepared in 45 vol% ethanol/water solution. (c), (d) TEM images of MoS_2 nanosheets and QDs prepared in DMF.

To investigate the effect of N-methylpyrrolidone (NMP) on the exfoliation of MoS_2, we also compared two other different solvents' effects under the same experimental conditions. They are N, N-dimethylformamide (DMF) and 45 vol% ethanol/water solution, respectively. The obtained nanosheets in the two solvents as shown in Fig. S1(a), (c) are similar to what have been reported before[2, 3]. The prepared QDs in 45 vol% ethanol/water as shown in Fig. S1(b) are of smaller size and lower crystallinity than that of MoS_2 QDs fabricated in NMP. In DMF, the yield of QDs is relatively low shown in Fig. S1(d).

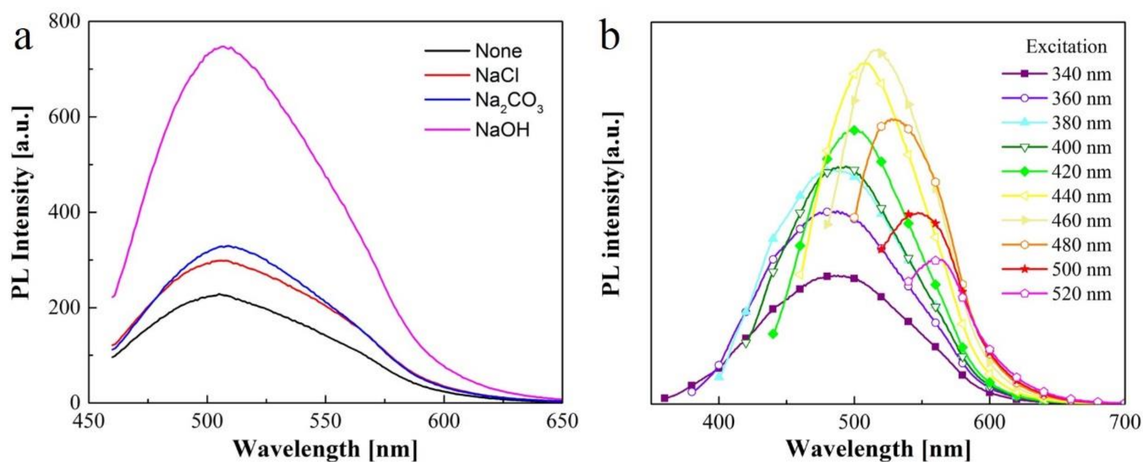

Fig.S2 (a) PL emission spectra of MoS_2 solution under 440 nm excitation with different additives. (b) PL emission spectra of MoS_2 solution in the presence of LiOH under different excitations.

The pH of the solution with the additive of NaCl, Na_2CO_3, NaOH was measured to be 4.8, 6.4 and 11, respectively, while the pH of solution with only MoS_2 was measured to be 4.7. The results indicate that both sodium ions intercalation and the alkaline environment contributed to the increase of the PL intensities. Moreover, the solution adding LiOH exhibited similar PL property to that adding NaOH.

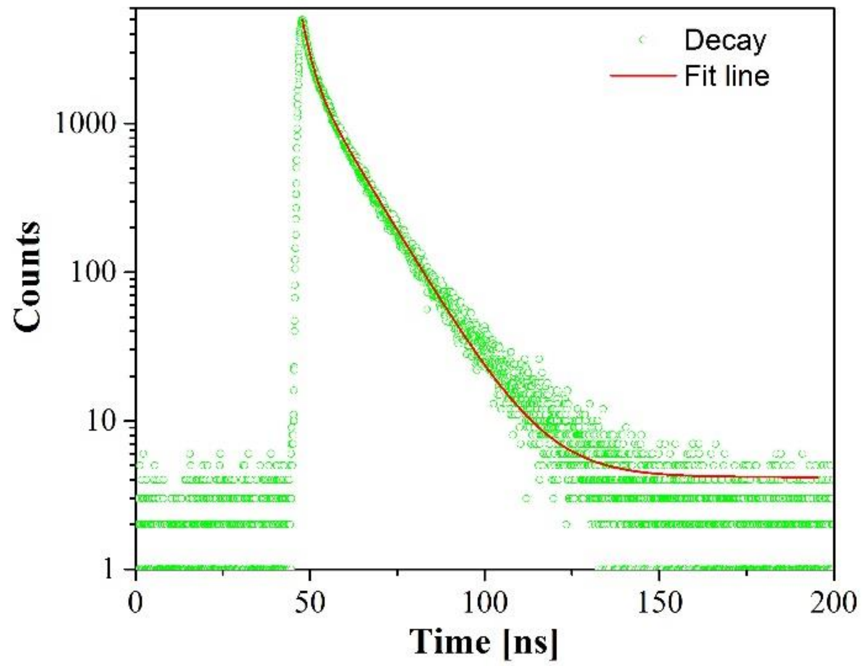

Fig.S3 The life time measurement of MoS_2 QDs sample

The decay was found to be 2 exponential and average life time for the sample was calculated to 5.4 ns.

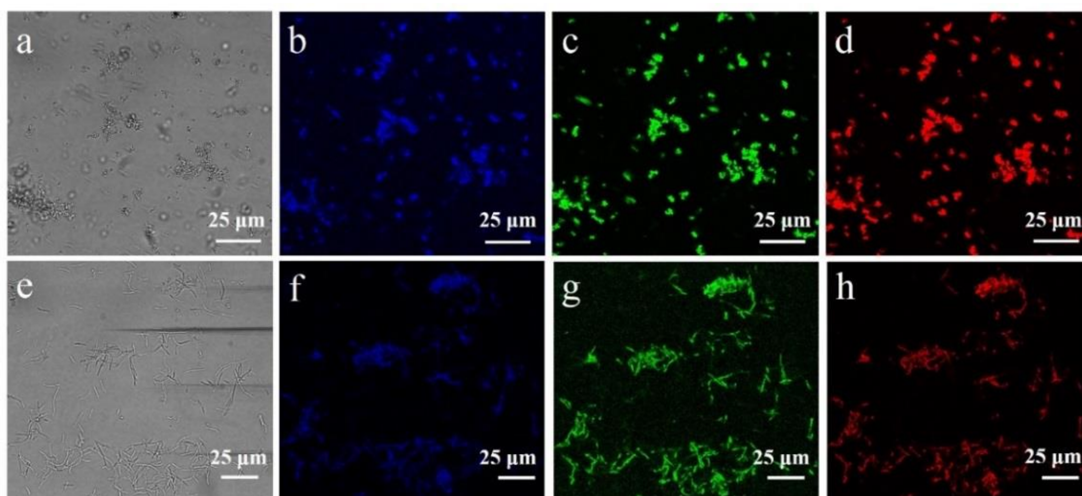

Fig.S4 Coliform bacteria (top) and staphylococcus aureus (bottom) imaged via MoS_2 QDs under bright field, 405 nm, 488 nm and 552 nm.

We employed MoS_2 QDs to image bacteria including coliform bacteria and staphylococcus aureus, respectively. The results show that MoS_2 QDs could mark the two bacteria clearly at different excitation wavelengths. Moreover, the change of intensity is consistent with that of lung cells. It also indicates that MoS_2 QDs can image bacteria with different surface structures.

Reference:

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