Synthesis of praseodymium-and molybdenum-sulfide nanoparticles for dye-photodegradation and near-infrared deep-tissue imaging

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Keywords: near-infrared fluorescence, deep tissue imaging, dye-photodegradation, fluorescein sodium salt

Supplementary material for this article is available online

Abstract

Development of nanoparticles with multi-functionalities is of great importance. In this study, praseodymium sulfide (Pr\(_2\)S\(_3\)) and molybdenum sulfide (MoS\(_2\)) nanoparticles were synthesized. The structural, morphological and optical properties of the as-obtained products were investigated by XRD, XPS, TEM, UV–vis–NIR spectroscopy, and photoluminescence spectroscopy. Pr\(_2\)S\(_3\) is found to be used in selective photodegradation of fluorescein sodium salt. MoS\(_2\) can be utilized for selective photodegradation of rhodamine B. In the mixture of rhodamine B, fluorescein sodium salt and rhodamine 6 G, most of rhodamine B and part of fluorescein sodium salt are optically degraded by Pr\(_2\)S\(_3\). In the mixture of rhodamine B, fluorescein sodium salt and rhodamine 6 G, part of fluorescein sodium salt and most of rhodamine B is degraded by MoS\(_2\). Moreover, they emit near-infrared fluorescence (800–1100 nm) when excited by the 785 nm light. Deep tissues imaging with high-contrast is shown, utilizing a nanoparticle-filled centrifuge tube covered with animal tissues (pig Bacon meat). Maximum imaging depth below the tissue surface of 1 cm is achieved. Our work provides a rapid yet efficient procedure to make nanoparticles for dual-application-potential in dye-photodegradation and near-infrared deep tissue imaging.

1. Introduction

Dyeing is widely utilized in textile plants for coloring clothes. Much attention should be paid to the issue that streams are facing grave problems because of the discharge of color wastewater from factories. It creates a severe environment for fish due to the toxicity of dyes existing in the wastewater. It is worth noting that dyes usually contain a synthetic origin and complex aromatic molecular structures. This makes them very stable and difficult to degrade. It is important to perform dye-pretreatment for the wastewater given that these dye materials would flow into our drinking water pipes if the wastewater wasn’t treated properly in the very beginning. Taking the aspect of environmental issue into account, the research activities about dye degradation are active [1–10]. One effective way for dye-pretreatment can be using photodegradation. More importantly, it is considered to be a green technology when organic pollutants are degraded under solar light or white light irradiation [1–10]. Praseodymium- and molybdenum-based material systems show their potentials for photodegradation of...
organic materials. Several examples can be found in photodegradation of methylene blue [1], rhodamine B [2], 2-naphthol [3], 2,4-dichlorophenol [4], methyl orange [5], nitrobenzene [6] and Eriochrome Black T [7], via Pr, N co-doped TiO2, PrFeO3, Pr6O11, Pr2O3, Pr:Y2SiO5, Pr:Y3SiO5 and Pr doped ZnO, respectively. Moreover, it is reported that Reactive Black 5, methylene blue/rhodamine B/methyl orange [9], can be optically degraded by MoS2 [8] and MoSe2 [9].

Furthermore, MoO3 is useful for the photodegradation of methylene blue [10]. These research endeavors inspire us that constructing materials based on Pr or Mo based entities can be effective for introducing photodegradation of the dyes. The making of nanoparticles to fulfill multiple tasks is of great interest, given that it can lower the cost in practical applications.

While the dye-photodegradation is one functionality of the materials that we are looking for, we still look for other potential applications.

Clinic practices involve with activities to perform inspection below tissue surface in order to find out the structure and function of the organs via using optical microscopy. It could be noted that deep tissue imaging of biological tissues is important for clinical applications. It helps doctors to acquire critical information of patients. Based on the imaging results, the doctors can decide the following treatment for the diseases.

However, there are many complex organic components existing in biological tissues, leading to strong optical absorption/scattering at specific wavelength region. It should be mentioned that light scattering generally exists on those spots under tissue surface. It lowers the imaging qualities, which makes the organs very difficult to be identified.

In order to overcome the obstacle of scattering tissues, one possible method is performing the imaging within near-infrared (NIR) window (750–1100 nm), which is superior comparing with the ultraviolet-visible region. It can improve imaging quality vastly since it involves with the using of fluorophores emitting and the achieving of low levels of photon absorption [11–16].

Therefore, in practical fluorescence imaging of the biological tissues, materials that process near infrared optical emission can be favorable. Their long-wavelength fluorescence can penetrate the thickness of the tissue and reach the imaging camera. These materials are very useful in deep-tissue imaging.

In the present study, praseodymium sulfide (Pr2S3) and molybdenum sulfide (MoS2) nanoparticles were synthesized. The structural, morphological and optical properties of the as-obtained products were characterized by x-ray diffraction (XRD), x-ray photoelectron spectroscopy (XPS), transmission electron microscopy (TEM), ultraviolet-visible-near-infrared (UV–vis-NIR) absorption spectroscopy, and photoluminescence spectroscopy. Three different dyes (rhodamine B, rhodamine 6 G and fluorescein sodium salt) are tested for photodegradation effect. It is found that Pr2S3 can be used for photodegradation of fluorescein sodium salt while MoS2 can be used for photodegradation of rhodamine B. Furthermore, they present NIR fluorescence (800–1100 nm) upon the 785 nm light excitation. Their deep-tissue imaging function is demonstrated, using a nanoparticle-loaded 2 ml centrifuge tube covered with animal tissues (pig Bacon meat). Maximum imaging depth below the tissue surface of 1 cm can be achieved. Our work shows the making of nanoparticles for dual applications in dye-photodegradation and NIR deep-tissue imaging.

2. Experimental

2.1. Materials

Fumaric acid, 2-methylimidazole, dimethylsulfoxide, L-cysteine, sulfuric acid, praseodymium (III, IV) oxide, molybdenum(VI) oxide, ethanol, rhodamine B, rhodamine 6 G and fluorescein sodium salt were all purchased from Alfa Aesar.

2.2. Preparation of precursors containing Pr and Mo

Praseodymium oxide (Pr2O3, 5 g) and sulfuric acid (85%, 20 ml) were mixed and stirred, then deionized water (50 ml) were added drop by drop. The acquired solution was heated with the temperature of 100 °C to get a clear Solution 1.

Molybdenum dioxide (MoO2, 5 g) and sulfuric acid (85%, 20 ml) were mixed and stirred, then deionized water (20 ml) were added dropwise. The acquired solution was heated with the temperature of 100 °C to get a clear Solution 2.

2.3. Preparation of organic precursors

Three types of organic solutions were prepared.

Solution 3 was made by dissolving 2-methylimidazole (2 g), terephthalic acid (5 g), fumaric acid (5 g), D(+)-glucose (5 g), oxalic acid dehydrate (5 g) in dimethylformamide (200 mL).
Solution 4 was prepared by mixing dimethyl sulfoxide (50 mL), oleic acid (40 mL), triethylamine (40 mL), diethylene glycol (40 mL), dimethyl sulfoxide (20 mL) and methacrylic anhydride (10 mL).

Solution 5 was done by dissolving L-cysteine (2 g) in de-ionized water (50 mL). Then Solution 3, Solution 4 and Solution 5 were mixed, some light yellow precipitate appeared. The mixture solution was stirred for 2 h to get a clear solution (Solution 6).

2.4. Preparation of Pr$_2$S$_3$ nanoparticles
Solution 1 (20 mL) was mixed with Solution 6 (80 mL). The mixture was stirred speedily for 2 h to get Solution 7. Solution 7 was firstly centrifuged with a speed of 6000 RPM for 0.5 h, then 10000 RPM for 0.5 h, followed by 14000 RPM for 0.5 h to get the final Pr$_2$S$_3$ nanoparticles.

2.5. Preparation of MoS$_2$ nanoparticles
The preparation of MoS$_2$ nanoparticles is similar to that of Pr$_2$S$_3$ nanoparticles. The only difference is the using of Solution 2 instead of Solution 1.

2.6. Preparation of several dye solutions
Preparation of dye solution FSS: Fluorescein sodium salt (0.1 g) was dissolved in deionized water (50 mL) to get the solution FSS.

Preparation of dye solution R6G: Rhodamine 6G (0.1 g) was dissolved in ethanol (50 mL) to get the solution R6G.

Preparation of dye solution RB: Rhodamine B (0.53 g) was dissolved in deionized water (100 mL) to get the solution RB.

Preparation of dye solution Dye 1: FSS (2 ml), RB (500 μl) and R6G (500 μl) was mixed and stirred to get the solution Dye 1.

Preparation of dye solution Dye 2: FSS (500 μl), RB (2 ml) and R6G (500 μl) was mixed and stirred to get the solution Dye 2.

2.7. Setup for photodegradation
A Halogen light bulb (Model: Double Ended Quartz FCL, OSRAM) with maximum output optical power 500 W is utilized for generating white light. The output optical power of the light bulb can be adjusted by a self-built controller.

The dye solutions prepared in section 2.6 were mixed with Pr$_2$S$_3$ or MoS$_2$ nanoparticles. The white light from the Halogen light bulb was shining on a glass tube filled with the mixture of Pr$_2$S$_3$ or MoS$_2$ nanoparticles and the dye solutions.

The dye solutions would change the color due to the photodegradation effect introduced by the nanoparticles. After photodegradation test was done in 30 min, the acquired dye solutions were collected for optical spectroscopy study.

2.8. Characterization
The XPS data was collected via a K-Alpha XPS instrument (Thermo Scientific). Powder XRD data was got from a PANalytical Empyrean XRD instrument. The XRD profile simulation and crystal structure derivation were done through a GSAS/DRAWxtl V5.5 software package. TEM images were obtained through a JEOL 1400 TEM (120 kV). The UV–vis–NIR absorption and UV–vis fluorescence spectroscopy were acquired through a SPARK optical spectrometer.

2.9. Setup of NIR fluorescence measurement
A self-built fluorescence measurement setup is utilized for collecting NIR fluorescence from the samples. A laser diode (Thorlab Inc.) provided the excitation light with the center wavelength of 785 nm. One optical fiber bundle was used as delivering the excitation light. Another optical fiber bundle was applied for collection of the fluorescence. They were combined in a probe, which was moved around the surface of the sample to collect the fluorescence. An NIR long-pass filter (Thorlab Inc.) was applied to get rid of the excitation light since the excitation light can be collected by the optical fiber bundle. The collected fluorescence was focused on a spectrometer (Ocean Optics).

2.10. Setup of NIR deep-tissue imaging setup
A 785 nm laser is used as an excitation light source. An optical fiber bundle is utilized to deliver the optical power. When the sample surface is shined by the laser, NIR fluorescence can emit from the sample surface. The image of the sample can be captured by a near infrared camera which is seating above the sample. Here, a
centrifuge tube filled with Pr$_2$S$_3$ or MoS$_2$ nanoparticles in ethanol (2 ml) solution was used as the imaging object. The centrifuge tube with first put in the position around the NIR camera to capture a control image. Then the centrifuge tube was covered with one layer of Bacon meat. The NIR camera was used to check the image of the centrifuge tube. Although the Bacon meat can block some of the NIR fluorescence emitting from the nanoparticles, some of the strong NIR fluorescence are able to penetrate through the Bacon meat and reach the NIR camera.

3. Results and discussion

3.1. XRD/TEM/XPS study

The XRD profiles were analyzed, which were confirmed as the phases of Pr$_2$S$_3$ and MoS$_2$. The XRD profiles can be found in figures S1 and S2 in supportive information is available online at stacks.iop.org/MRX/7/036203/mmedia.

TEM was used to find out the morphology and size of the nanoparticles (see figures 1(a)–(b)). The Pr$_2$S$_3$ nanoparticles show spherical shape. The MoS$_2$ nanoparticles present rectangular shape. The nanoparticle size distribution is shown in figure S3 in supportive information.

XPS was applied to study the core levels, valence band and chemical bonding information of the samples. Figures 2(a)–(b) show the XPS high scanning spectra for Pr$_2$S$_3$. Pr 3d spectra (figure 2(a)) reveal peaks at 933.3 eV, 943.6 eV, 953.9 eV and 964.3 eV. The 933.3 eV and 953.9 eV peaks are attributed to the main peaks of Pr 3d$_{5/2}$ and Pr 3d$_{3/2}$. The other two peaks at 943.6 eV and 964.3 eV (denoted as 'A' and 'B' in figure 2(a)) are considered as the satellite peaks, which is caused by the effect of the covalency hybridization as well as the multiplet effect associated with some modification of the spectral shape and broadening [17, 18]. The deconvolution of S 2p spectra (figure 2(b)) present peaks at 167.9 eV and 168.9 eV, which are assigned to S-Pr bonding and S-S-Pr bonding, respectively [19–21].

Figures 3(a)–(b) present the XPS high scanning spectra for MoS$_2$. Figure 3(a) depicts the Mo 3d spectra, which present peaks at 231.1 eV, 232.2 eV, 234.3 eV and 235.3 eV. The 232.2 eV and 235.3 eV peaks are assigned to the core levels of Mo 3d$_{3/2}$ and Mo 3d$_{5/2}$, separately [22]. The 231.1 eV and 234.3 eV peaks are considered as satellite peaks. S 2p spectra are depicted in figure 3(b), which presents peaks at 167.6 eV and 168.6 eV. The 167.6 eV peak is assigned to S-Mo bonding. The 168.6 eV peak is considered as the effect of S-S-Mo bonding [19–21].
3.2. Optical property

The studies of optical absorption and fluorescence were done for better understanding of the samples. Figures 4(a)–(f) plot the optical absorption and fluorescence generated by various light sources. The absorption spectra (see figure 4(a)) for both samples show a shoulder around 260–380 nm and a major absorption peak around 907 nm. The absorption of Pr$_2$S$_3$ is higher than MoS$_2$ in the ultraviolet-visual light range (around 298 nm-750 nm).

Both samples show polychromatic-photoluminescence upon 280 nm, 380 nm, 480 nm, 580 nm and 785 nm light excitation (figures 4(b)–(f)). The fluorescence intensities of MoS$_2$ generated by 280 nm, 380 nm and 480 nm light of MoS$_2$ are higher than those of Pr$_2$S$_3$. However, the fluorescence intensities of MoS$_2$ generated by
580 nm and 785 nm light are lower than those of Pr$_2$S$_3$. Upon 785 nm light excitation, both samples show NIR fluorescence covering from 794.06 nm to 1143.60 nm. The fluorescence spectra show a peak at 808 nm. This can be used for the purpose of NIR deep-tissue image which will be discussed later.

3.3. Photodegradation of dyes

Figure 5 shows the photodegradation test of dye through Pr$_2$S$_3$ and MoS$_2$ nanoparticles. The photodegradation changes the color of the dye and dye mixture in the bottles of a, b, c, d, e, f, g and h. Bottle a is filled with the fluorescein sodium salt solution without any photodegradation treatment. b: Fluorescein sodium salt solution without photodegradation treatment after photodegradation treatment via Pr$_2$S$_3$ nanoparticles. c: Dye 1 solution without any photodegradation treatment. d: Dye 1 solution after photodegradation treatment via Pr$_2$S$_3$ nanoparticles. e: Rhodamine B solution without photodegradation treatment. f: Rhodamine B solution after photodegradation treatment via MoS$_2$ nanoparticles. g: Dye 2 solution without photodegradation treatment. h: Dye 2 after photodegradation treatment via MoS$_2$ nanoparticles. Here, Dye 1 and Dye 2 are made by the mixture of rhodamine B, rhodemaine 6 G and fluorescein sodium salt (see the ‘Experimental’ section for detail preparation).

Figure 5.

Figure 6. Pr$_2$S$_3$ can be used for photodegradation treatment of fluorescein sodium salt under white light irradiation. The purple curve is the original fluorescence of fluorescein sodium salt excited by the 440 nm light (the ‘Control’). After optical degradation treatment via Pr$_2$S$_3$ nanoparticle, the intensity of the fluorescence is significantly decreased (the yellow curve).

Figure 6.

580 nm and 785 nm light are lower than those of Pr$_2$S$_3$. Upon 785 nm light excitation, both samples show NIR fluorescence covering from 794.06 nm to 1143.60 nm. The fluorescence spectra show a peak at 808 nm. This can be used for the purpose of NIR deep-tissue image which will be discussed later.

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After photodegradation treatment via Pr$_2$S$_3$ nanoparticles, its color is changed to be dark grey (see Bottle b in figure 5). Figure 6 clearly presents the change of fluorescence spectra after photodegradation test. Fluorescence spectra of Bottle a show a strong peak at 525.18 nm when excited by 440 nm light (purple curve in figure 6). The fluorescence intensity of Bottle b excited by 440 nm light drops dramatically and the peak shifts to 515.78 nm (see yellow curve in figure 6). The photodegradation effect of dye mixture is also investigated. Bottle c in figure 5 is filled with Dye 1, which is the dye mixture of rhodamine B, rhodemaine 6 G and fluorescein sodium salt.

Its color is dark red. Clearly, the photodegradation treatment with Pr$_2$S$_3$ nanoparticles changes its color to light yellow (see Bottle d in figure 5). Figure 7(a) presents fluorescence of Bottle c and d in figure 5 excited by 440 nm light. The fluorescence of Bottle c reveals two major peaks at 524.08 nm and 575 nm. The fluorescence of Bottle d only shows one peak at 515.38 nm. It should be noted that Pr$_2$S$_3$ nanoparticles have been filled into the
three bottles which contain rhodamine 6 G, rhodamine B and fluorescein sodium salt separately for photodegradation test. It is found that Pr$_2$S$_3$ can be selectively to degrade the fluorescein sodium. However, when these three kinds of dyes were mixed together (see Bottle c in figure 5), not only the fluorescein sodium salt but also the rhodamine B was degraded. As show in the bottle d in figure 5, no red color (introduced by the rhodamine B) is observed. This is also supported by the fluorescence spectra analysis. Figures 7(b) and (c) present the fluorescence spectra of rhodamine B and rhodamine 6 G excited by 440 nm light. It can be found that the rhodamine B spectra show a red light peak at 623.5 nm; the rhodamine 6 G spectra show a green light peak at 521.65 nm; the fluorescein sodium salt spectra show a green light peak at 524.6 nm. Interestingly, in figure 7(a), there is only one green light peak at 515.4 nm left, which may be due to the combination effect of the fluorescein sodium salt and the rhodamine 6 G. The peak at 623.5 nm generated from the rhodamine B is absent. It indicates that most of the rhodamine B and part of the fluorescein sodium salt are optically degraded by Pr$_2$S$_3$ nanoparticles.

MoS$_2$ nanoparticles are tested separately for their photodegradation impact on rhodamine B, rhodemaine 6 G and fluorescein sodium salt. It is found that MoS$_2$ can be selectively to degrade rhodamine B. As shown in figure 5, Bottle e, the rhodamine B solution, has shown a red color. After degraded by MoS$_2$ nanoparticles, its color becomes cyan. The photodegradation effect introduced by MoS$_2$ is evident through fluorescence study. Figure 8 presents fluorescence spectra of bottle e and f by using 480 nm light excitation. The fluorescence spectra of Bottle e show a peak at 600.72 nm. The fluorescence spectra of Bottle f present a peak at 582.6 nm. Further more, the intensity of the 600.7 nm peak is much higher than that of the 582.6 nm peak.
MoS\textsubscript{2} is tested for photodegradation of the dye mixture (Dye 2). As shown in figure 5, the original color of Dye 2 is light red (see Bottle g in figure 5). After degraded by MoS\textsubscript{2}, its color is light yellow (see Bottle h in figure 5). Figure 9 shows fluorescence investigation of the dyes and their mixture upon 480 nm light excitation. Fluorescence spectra of rhodamine 6 G, rhodamine B and fluorescein sodium salt reveal a peak at 580.9 nm, 596.6 nm and 530.2 nm, respectively. Fluorescence spectra of the mixture (Dye 2) depict two peaks at 529.3 nm and 580.6 nm. After degraded by MoS\textsubscript{2}, it shows one peak at 538.7 nm. The intensity of the 538.7 nm peak is much lower than that of the 530.23 nm peak generated by fluorescein sodium salt. The 596.58 nm peak generated by rhodamine B is totally eliminated. Therefore, it indicates that part of fluorescein sodium salt and most of rhodamine B are degraded by MoS\textsubscript{2}. Since the intensity of the 580.9 nm peak generated by rhodamine 6 G is very weak, it is hard to tell whether rhodamine 6 G is degraded or not.

Taking the above into account, several facts can be considered: (a) Pr\textsubscript{2}S\textsubscript{3} can be applied for selective photodegradation of fluorescein sodium salt. (b) MoS\textsubscript{2} can be used for selective photodegradation of rhodamine B. (c) In the mixture of rhodamine B, fluorescein sodium salt and rhodamine 6 G, most of rhodamine B and part of fluorescein sodium salt are optically degraded by Pr\textsubscript{2}S\textsubscript{3} nanoparticles. (d) In the mixture of rhodamine B, fluorescein sodium salt and rhodamine 6 G, part of fluorescein sodium salt and most of rhodamine B is degraded by MoS\textsubscript{2}.

### 3.4. Deep-tissue imaging

A Bacon meat model is used for demonstration of the deep-tissue imaging. A 2 ml centrifuge tube is filled with Pr\textsubscript{2}S\textsubscript{3} or MoS\textsubscript{2} nanoparticles in ethanol solution for the study of deep-tissue imaging. The nanoparticles can emit NIR fluorescence covering from 800 nm to 1100 nm upon 785 nm light excitation. Therefore, the images of the tube can be captured by a NIR camera. Even the tube is covered by several layers of Bacon meat, part of the NIR fluorescence can still travel through the Bacon meat and reach the NIR camera. This generates the images of the tube.

Figure 10(a) is a control image captured via a 2 ml centrifuge tube which is filled with Pr\textsubscript{2}S\textsubscript{3} solution. When it is covered by 1 layer of Bacon meat, the shape of the very sharp edge of the tube can be seen (see figure 10(b)). As shown in figure 10(c), when 2 layers of Bacon meat are used, the image is blurred. Finally, when 5 layers of Bacon meat are applied, the shape and edge of the tube could still be identified (see figure 10(f)). The result of using MoS\textsubscript{2} for deep-tissue imaging is similar (see figures 11(a)–(f)). The total thickness of 5 layers of Bacon meat is 1 cm, which indicates that the imaging depth of 1 cm is obtained.

Figure 12(a) depicts the corresponding fluorescence spectra of Pr\textsubscript{2}S\textsubscript{3} solution filled 2 ml centrifuge tube after covering with various layers of Bacon meat. It can be seen that the intensity of the 808 nm peak drops when the layer thickness increases (see figure 12(b)).

Figure 13(a) presents the corresponding fluorescence spectra of MoS\textsubscript{2} filled 2 ml centrifuge tube after covering with various layers of Bacon meat. The intensity of the 808 nm peak decreases when the layer thickness increases (see figure 13(b)). Here, due to the limit and resolution of our instrument, the data about the fluorescence spectra and peak intensity of MoS\textsubscript{2} filled 2 ml centrifuge tube after covering with 5 layers of Bacon meat is absent.

Optical coherence tomography (OCT) is generally applied in clinic practices when deep tissue imaging is required. Yet it has shown a very restricted imaging depth of 1–2 mm below the tissue surface. Development of new technologies or materials are in great demand for the deep tissue imaging.
Our NIR fluorescence imaging strategy combined with the synthesized nanoparticles is able to achieve the imaging depth of 1 cm. It can be noted that the potential application of these nanoparticles in NIR deep-tissue imaging is tremendous. They are envisioned to be used as active image contract agents in bio-medical imaging systems. Our future endeavor can be focused on their combination with endoscopes or optical fiber bundles, which can be useful in dental surgical operation. They enable the remote measurement of the morphology of the dental tissue. Our future work can be continuing to use these materials for testing their ability in dual modes tumor tissue imaging by combing magnetic sensitive materials and using animal model [23, 24].
4. Conclusion

Two types of nanoparticles (Pr$_2$S$_3$ and MoS$_2$) were synthesized. XRD, XPS, TEM, UV–vis-NIR spectroscopy and photoluminescence spectroscopy were applied to find out their structural, morphological and optical properties. They present polychromatic-photoluminescence upon the 280 nm, 380 nm, 480 nm, 580 nm and 785 nm light excitation. Pr$_2$S$_3$ can be used for selective photodegradation of fluorescein sodium salt. MoS$_2$ can be utilized for selective photodegradation of rhodamine B. In the mixture of rhodamine B, fluorescein sodium salt and rhodamine 6 G, most of rhodamine B and part of fluorescein sodium salt are optically degraded by
In the mixture of rhodamine B, fluorescein sodium salt and rhodamine 6 G, part of fluorescein sodium salt and most of rhodamine B is degraded by MoS$_2$. They emit NIR fluorescence (800–1100 nm) when excited by the light of 785 nm. They can be used for NIR deep-tissue imaging. Maximum imaging depth below the tissue surface of 1 cm can be achieved. Our methodology of making these nanoparticles relies heavily on a solution synthesis approach. It may be cheaply and easily to be used in industry, where the normal hydrothermal approach. It may be cheaply and easily to be used in industry, where the normal hydrothermal synthesis that used autoclaves can lead to high cost of fabrication. This study demonstrates the fabrication of the nanoparticles for dual applications in dye-photodegradation and NIR deep-tissue imaging.

Acknowledgments

The help from Ms Ying Xiao in Share Instruments Facility-Louisiana State University, Mr Kai Zhou in Instruments centers-Chongqing University and Dr Hao Fu from McGill University is appreciated. The financial support from the following agents is very appreciated: China National Key R&D Program (2017YFB1103202), Jiangsu State R&D Program (BE2018010), Key Program Special Fund in XJTU (KSF-E-39), XJTU Research Development Fund (RDF-18–02–20). Chongqing Research Program of Basic Research and Frontier Technology (No. cstc2017jcyjAX0469), LSU Leveraging Innovation for Technology Transfer (LIFT2) Grant: LSU-2019-LIFT-003, Louisiana Research Competitiveness Subprogram (RCS), Board of Regents Support Fund (BoRSF): LEQSF (2018-21)-RD-A-09 and LSU Biomedical Collaborative Research Program (008481).

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