Ultrafast Synthesis of MoS₂ Quantum dot Particles using Low Energy at Room Temperature

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Abstract

In this study, a new method of synthesizing large amount highly fluorescent MoS₂ quantum dots is presented. This low environmental impact ,ultrafast ,saving energy method can synthesize a large number of MoS₂ quantum dots(QDs). Using the NaCl crystal particles sharp edge that are insoluble in the supersaturated NaCl solution combined with the shear force generated by the press shaker to cut the MoS₂ bulk material to form MoS₂ QDs.Large amount highly fluorescent MoS₂ quantum dots in a matter of 3 min using the NaCl crystal as a sustainable cutting agent.The prepared MoS₂ QDs were characterized by TEM ,FESEM ,EDX ,DLS ,XPS, UV-vis Spectroscopy ,Florescence Spectroscopy analyses. Furthermore, this ultrafast, low energy consumption,green process may offer a potential major advance for production of other QDs materials from bulk material.

Introduction

In recent years, the Typical layered transition metal dichalcogenide (TMD) material including MoS₂ has received a lot of attention because it is a very promising material that can be used in quick virus screening [1] Uric acid sensor[2] ion sensing[3] chemical sensing for the quick detection of deleterious explosives[4] bio-imaging[5].

Now a days, there are many different ways to synthesize quantum dot materials. There are top down and bottom up methods for making quantum dots. In particular, the top down method can produce quantum dot materials in a large amount with low energy consumption [6–8].

However, the methods mentioned above to produce quantum dots all have the disadvantages of complex synthesis process, long time, toxicity of solvents, and high energy consumption. The use of high energy will damage structure of the quantum dots to cause defects in the quantum dots .The use of low energy methods to produce QDs materials cannot produce QDs materials quickly. At present, there is no method to produce QDs materials with the advantages of eco-friendly,low defects, ultra-fast and mass production.Therefore,it is highly necessary to develop a new process for a low defects,ultra-fast,mass production ,non-toxic, facile,environmentally friendly, low energy consumption preparation process synthesis of MoS₂ QDs .

Herein, NaCl is used as a cut and exfoliate agent is performed to produce MoS₂ QDs from the MoS₂ bulk material. Using the NaCl cutting method to generate MoS₂ quantum dots only consumes very low energy, it is does not damage the material structure to produce defects, and can quickly generate a large number of quantum dots materials.The production method of rapid screening materials for coronavirus needs to be large and fast. Therefore, this method is expected to be applied to current rapid screening materials for coronaviruses.In this study, a novel low-energy, ultra-fast, and eco-friendly method was discovered to prepare a large number (2–6 nm) of low-defect MoS₂ QD. This method uses only 95% ethanol in experimental section.

Materials

MoS₂ bulk powder (average particle size: 100 nm, Mol. Wt. 160, purity 99.0%) was purchased from Graphene Supermarket. NaCl was purchased from Tian jing Guangfu Technology Development Co., Ltd., China. 95% Ethanol was purchased from EHO chemical Co., Ltd., All reagents were of analytical grade and used without further purification.

Preparation of MoS₂ quantum dots(QDs)

According to reported [9] that the MoS₂ breaking strength is about 16–30 GPa. The NaCl crystallites could transfer the shear force (shear force produced by pressing shaker). The running speed of 2500 rpm is converted into a shear force is about 20–180 GPa, through the NaCl crystallites sharp edges and even the corners, which surface of MoS₂ bulk receives sufficient shear strength to break it. The fabrication process of the MoS₂ QDs was illustrated in Figure 1. MoS₂ QDs were obtained by crystalline with sharp edges NaCl insoluble particle cutting treatment of bulk MoS₂ powder. The dissolved Na⁺ (1.78 Å⁰) and Cl⁻ (1.95 Å⁰) can penetrate into the interlayer due to the ion size is smaller than the MoS₂ (6.5 Å⁰) layer and the interlayer gap can be exfoliation. In a typical process, mix a large amount of MoS₂ powder and NaCl with ethanol in a glass bottle. After 2500 rpm (vtx-3000I vortex mixer) pressing shaker attachment for 3 min at 25 °C. Then, the mixture was centrifuged at a speed of 6000 rpm for 3 min to collect the top solution and remove the bottom unexfoliated MoS₂ bulk material. The MoS₂ QDs solution with strong blue luminescence under 365 nm UV light excitation, respectively in Fig. 1.

Samples characterization

A field emission scanning electron microscope (FESEM, Hitachi, S-4800) and an energy dispersive X-ray spectrometer (EDS, HORIBA, EX-350) were used to characterize the size distribution and morphology of MoS₂ quantum dots. Use JEOL JEM-2010 to acquire high-resolution transmission electron microscope (HRTEM) images. The UV-Visible spectrum was analyzed on Hitachi U-3900 Spectrophotometer (Japan). The PL spectrum of MoS₂ QDs was measured with a Horiba Jobin Yvon Fluoromax-4 fluorescence spectrophotometer. The particle size distribution of MoS₂ QDs was measured by dynamic light scattering (DLS). Use (Thermo Fisher Scientific) K-Alpha X-ray photoelectron spectrometer to measure the atomic state of the element.

Results And Discussion

Dynamic light scattering (DLS) analyzer was used to characterize the particle size distribution of the MoS₂. It can be confirmed by the DLS particle size distribution results as shown in Fig. 2 that the particles have good monodispersibility, and its diameter is in the range of 3–6 nm.

It can be observed from the SEM image in Fig. 3 that the size of the uncut MoS₂ bulk material particles that the MoS₂ bulk material is very aggregated and it cannot

be seen that it is in the form of particles.

According to reported [9] that the MoS₂ breaking strength was is about 16 – 30 GPa. The NaCl crystallites could transfer the shear force (shear force produced by pressing shaker) The running speed of 2500rpm is converted into a shear force of about 20-180GPa, this shear force transfer to the edge of the NaCl particles is enough to make the MoS₂ bulk break into MoS₂ QDs .The results indicated MoS₂-QDs Successfully synthesized by using NaCl cutting method, confirmed by scanning electron microscope (SEM) micrograph show in (Fig. 4b,c). The particle size of MoS₂ QD about range in 2-6nm. The square NaCl particles show in Fig. 4a have cut MoS₂ QD on the surface. Figure 4b show NaCl cutting MoS₂ bulk evidence. Figure 4b can prove that NaCl can use its sharp edges to cut large particles MoS₂ into MoS₂ QD. MoS₂ bulk after cutting produces MoS₂ QD attached to NaCl square surface in red cycle. In Fig. 4d, the EDS spectra of MoS₂-QD respectively show two elements (including Mo, S, and) uniformly distributed.

Figure. 5a shows the high-resolution transmission electron microscope image of MoS₂ QDs. The TEM image contains more than 100 MoS₂ QDs. From the figure, it can be observed that the method for preparing quantum dots developed in this research can effectively prepare a large number of quantum dots. TEM measurement showed that MoS₂ quantum dots size are between 3 and 10nm show in (Fig. 5a). The high-resolution TEM (HRTEM) image (Fig. 5b) shows the high crystallinity of MoS₂ QDs with a lattice parameter of 0.27 nm, which is consistent with the (100) diffraction surface of MoS₂. This result shows that MoS₂ QDS still maintains the same crystallinity as MoS₂ bulk.

Figure 6 shows the photoluminescence spectra excited at 365 nm of MoS₂-QDs solution at room temperature. emission peak located at 480 nm at this excitation wavelength can be considered from the PL spectrum. The intensity of PL spectrum is arrive 3000. This data shows that this preparation method will not damage the structure of MoS₂ to produce defects.

The MoS₂ optical properties show in Fig. 7. Measure the optical properties of MoS₂ QDS by UV-visible. The absorption wavelength of MoS₂ is less than 300nm ($\lambda < 300$ nm), with a tail extending into the visible range, assigned to the excitonic features of MoS₂ QDs. The calculated MoS₂ band gap is 4.19ev and band gap more than single-layer MoS₂(1.9ev) and bulk MoS₂(1.2ev). The inset image of Fig. 7 shows that quantum dots can be very stably dispersed in ethanol solution for one month as demonstrated by the Tyndall effect in the form of a typical discernible green line resulted from light scattering when a laser beam shines through the MoS₂ solution.

The atomic states of Mo and S in MoS₂ QDs are analyzed by Xray photoelectron spectroscopy (XPS). The results are shown in Fig. 8a and 8b have four peaks as Mo 3d_{3/2}(234.8 eV), Mo 3d_{5/2} (231.8 eV), S 2p_{1/2}(168.5 eV) and S 2p_{3/2} (167.5 eV), respectively, indicating the 2H MoS₂ phase in the crystal structure. Two characteristic peaks situated at 231.8 (Mo 3d_{5/2}) and 234.8eV (Mo 3d_{3/2}) are typical values for Mo⁴⁺ in MoS₂ (Fig. 8a).

Conclusions

We have successfully synthesized a large number of MoS₂ quantum dot materials under ultra-fast time and low environmental impact conditions. This ultrafast and facile method has the potential to be applied to the production of other kinds of quantum dots. This method can be potentially scaled up to produce high quality and uniform MoS₂ QDs in high concentration at short time.

Declarations

Conflicts of interest

The authors declare that they have no competing interests.

Acknowledgments

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MY3).

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Figures

Figure 1

Process illustration for the preparation of MoS2 QDs by using crystalline with sharp edges NaCl particle cutting treatment.

Figure 2

Dynamic light scattering (DLS) particle size distributions of MoS2 QDs

Figure 2

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SEM image of MoS₂ bulk without NaCl cutting treatment According to reported [9] that the MoS₂ breaking strength was is about 16–30 GPa.

Figure 4

SEM images of (a) NaCl particles(b) NaCl cutting MoS₂ Bulk evidence as show in red cycle image and (c) MoS₂ QDS (d) EDS spectrum of M-QDs.

Figure 5

(a) High resolution TEM image of MoS₂ QDs showing good concentration and uniformity. (b) most of the QDs are in range of 3–10 nm, Magnified TEM image showing the lattice spacing 0.27 nm

Figure 6

The PL spectra of the MoS2-QDs measured under the excitation of 360 nm

Figure 7

UV-vis spectra of MoS2 QDs inset fig: Tyndall effect of MoS2 QD aqueous solution

Figure 8

(a) Mo 3d and (b) S 2p XPS spectra of MoS₂ QDs.