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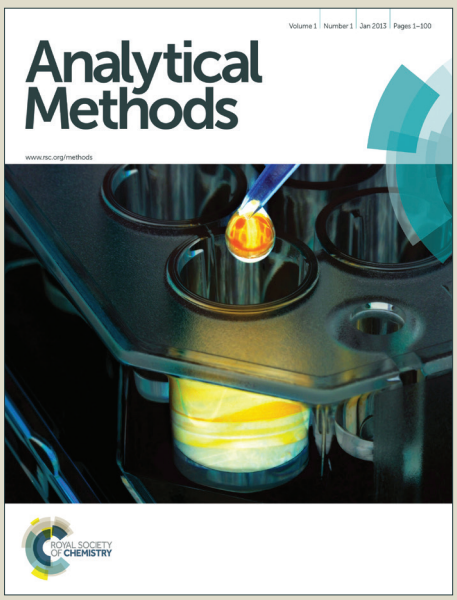





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# Probing the cytotoxicity of CdS-MPA and CdSe-MUA QDs on the bacterial pathogen *Staphylococcus aureus* using MALDI-MS

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**Abstract:**

Two quantum dots, CdS QDs capped with "mercaptapropionic acid" (MPA) and CdSe capping with "mercaptaundecanoic acid" (MUA) were synthesized and their toxicity against the well known bacterial pathogen, *Staphylococcus aureus* was compared using matrix assisted laser desorption/ionization mass spectrometry (MALDI-MS), Epifluorescence Microscopy and spectrophotometeric analysis (O.D600nm). CdS-MPA QDs were observed to be more compatible compared to CdSe-MUA QDs. The CdSe-MUA QDs were toxic at all concentrations and at incubation time < 3h too. It was also observed that the CdS-MPA QDs were not entirely biocompatible, but exhibited toxicity at concentrations > 0.5mg/mL after prolonged incubation (>12h). The epifluorescence technique confirmed the results which have been observed in the MALDI-MS studies.

**Keywords :** CdS-MPA, CdSe-MUA, MALDI-MS, Epifluoresence microscope, *Staphylococcus aureus*

## Introduction

Semiconductor nanocrystals or quantum dots (QDs) have a characteristic fluorescence which is higher than the organic fluorophores[1-2]. QDs exhibit fluorescence which can be applied for biological and biomedical diagnosis[3]. Size manipulation of QDs at nano sized level influences their functional properties, which is not observed in the bulk materials. When the QDs are attached to peptides or antibodies, they can be used to locate or target specific tumor sites for releasing drugs[4]. QDs have large surface area to volume ratios for the attachment of different biomolecules like antibody or DNA, so they can be used as effective probes for cellular or in vivo imaging. Mono-dispersed luminescent QDs encapsulated in stable polymers have also been reported for imaging applications[5].

QDs are nanocrystal particles with sizes ranging from 2-10 nm, and they may contain about 200-10,000 atoms. Different sizes of semiconductor QDs typically release different colors of radiations which can be applied in biological or biomedical detections based on their color changes[6]. QDs typically have a small energy gap, therefore they exhibit strong luminescence depending on their sizes[7]. They are about 10 times brighter than the organic dyes and fluorescence proteins, with 100-1000 times photo stability[8].

Several studies on QDs have reported their toxicological effects including the effects on cell viability, when used in *In vivo* experiments. The cytotoxicity related parameters of QDs is dependent on various factors including: size, concentration of QDs, surface capping agents of QDs, color, surface chemistry and method of preparation[9-10]. The toxicological effects of QDs may be attributed to free radical generation. These heavy semiconductor metals are toxic to the liver and kidney as they can easily penetrate human organs[11]. To make the QDs biocompatible they are synthesized in the aqueous media, encapsulation with amphiphilic polymers or thiol groups has been reported[12-14].

MALDI-MS developed by Karas and Hillemkamp which is a very useful tool for fast analysis of biological samples. Biomolecules can be detected on the basis of their molecular weight and fragmentation patterns[13]. MALDI-MS has also been widely applied for the characterization of microorganisms[15-17]. Its capability to rapidly identify and characterize microorganisms is important in biomedicine and clinical applications. The intact bacterial cells can be analyzed using MALDI-MS, such analysis can produce characteristic mass fingerprints of bacteria which can be employed for rapid bacterial identification[17-18]. MALDI-MS has been demonstrated by our group workers[19-20] to probe the killing and bactericidal activity of nanoparticles based on the

suppression of the protein peaks in the MALDI-MS spectra. In the present study, we synthesize CdS QDs functionalized with MPA and CdSe QDs functionalized with MUA. Their toxicity against the well known bacterial pathogen, *Staphylococcus aureus* was compared using the MALDI-MS, spectrophotometry and Epifluorescence Microscopy as the probing tools. In the following study, we determine the critical concentrations of both the QDs which can result in the death of the bacterial cells. We also assess the concentration upto which the QDs can be compatible to the bacterial cells. As it has MPA and MUA as capping agent which function as a stabilizer for easy dispersion of the QDs and also as a linker for its attachment with other biomolecules. As these are a significantly important class of QDs, to understand their toxicity properties is interesting and what we seek to explore in this study.

## Materials and methods

### Chemicals

All chemicals used in this experimental study were of purity more than 98%. Se powder (99%), Cadmium nitrate tetrahydrate, 3-mercaptopropionic acid (MPA), Sodium sulphide were purchased from Fluka (Buchs, Switzerland). 11-Mercaptaundecanoic acid from Aldrich. Sodium borohydride bought from Koch-light laboratories ltd, (Colnbrook-Bucks, England). Ammonium hydroxide from J.T.Baker, USA. Sodium sulfide anhydrate was obtained from Nihow Shiyak Industries Ltd., Japan. 3,5-dimethoxy-4-hydroxycinnamic taken from Alfa Aesar, Britain. Acetonitrile, hydrochloric acid and trifluoroacetic acid (TFA) were purchased from Wako Pure Chemicals (Osaka,Japan). The water used for the experimental purpose including the cleaning of glass wares were used from a Milli-Q water purification system (Millipore, Bedford, MA, USA).

### Instrumentation

Transmission electron microscope (TEM) images were obtained using a Philip CM200 (Switzerland) at accelerating voltage 75keV. The UV-Visible spectra of the CdSe-MUA/CdS-MPA QDs were recorded using a double beam UV-VIS spectrophotometer (U3501, Hitachi, Japan) between 280-500 nm. The fluorescence emission spectra of the functionalized CdSe-MUA/CdS-MPA QDs were recorded using the fluorescence spectroscopy (Hitachi, F-2700 fluorescence spectrophotometer) at slit width 15nm. A vortex agitator (VM,2000, Digisystem Laboratory, Taipei, Taiwan) was used for proper mixing of the sample solution with the matrix solution. The pH was measured using a digital pH meter (Istek Model 720P, South Korea). A

Microflex MALDI-TOF mass spectrometer (Bruker Daltonics, Bremen, Germany) was used for the analysis of the QDs toxicity on *Staphylococcus aureus*. All the data were recorded in linear/positive-ion mode. MS system was operated using a pulse nitrogen laser (337nm, 4-nsec pulses at 10.0Hz) and the experiment was done by applying laser at 60.0μJ. The accelerating voltage was 20kV and a 96 well MALDI target plate was used and MALDI-MS spectra was acquired by applying 300 laser pulses. All experiments were performed in triplicate to confirm consistency.

**Synthesis of CdS-MPA quantum dots**

CdS-MPA QDs were prepared as mentioned in the previous literature. Briefly, 400μL of 3-MPA was transferred into a 250 mL round bottom flask containing 15 mL of deionized water. To this, 2 mL of 0.01 M cadmium nitrate solution was added drop wise under $N_2$ pressure with constant stirring for 1 h. The pH of the solution was adjusted to 9.0 by adding ammonium hydroxide solution. 2.5 ml of 0.008 M sodium sulphide solution was quickly added to the above solution at 96℃ and the solution was stirred for 2 h. The clean green-yellowish CdS-MPA QDs solution was stored at 4℃ until further use.

**Synthesis of CdSe-MUA quantum dots**

CdSe-MUA QDs was also synthesized according to previous literature[11]. Briefly, 0.0228gm of $CdCl_2$ and 0.0524 gm of mercaptaundecanoic acid (MUA) were dissolved into 125mL of deionized water. 1M solution of NaOH for maintaining the pH 11.00 was prepared, then this solution was transferred to another 250mL round bottom 3 necked flask. The previous solution was degassing by passing $N_2$ gas for 30 min. The NaHSe solution was obtained through the reaction of selenium powders with $NaBH_4$. The molar ratio $Cd^{2+}$/$HSe^-$/MUA solution was stirred using a magnetic stirrer and then freshly prepared NaHSe solution was added using a microsyringe. This solution was refluxed for 2 h at 96℃ to obtain CdSE-MUA QDs.

**Bacterial Culture preparation and interaction with QDs.**

One colony of *Staphylococcus aureus* was picked up using a sterile loop from a freshly prepared 24 h old streak plate pure culture and inoculated into 1L of liquid broth medium and incubated for 12 h. This is the stock inoculum. To 20mL of freshly prepared autoclaved sterile liquid nutrient broth medium, 1mL of the inoculum was added from the stock culture (Ke Y et al. 2010). These flasks were amended with different concentrations of CdSe-MUA and CdS-MPA

QDs (0.00mg/mL, 0.01mg/mL, 0.02mg/mL, 0.04mg/mL, 0.05mg/mL, 0.1mg/mL, 0.2mg/mL, 0.4mg/mL and 0.5mg/mL) respectively. The QDs added in bacterial culture containing flasks were incubated in a shaker cum incubator at 37ºC. Samples for MALDI-MS analysis were collected after 3h, 6h, 9h and 12 h incubation times. 1mL of bacterial culture was taken for MALDI-MS analysis in eppendorf tubes and centrifuged at 10,000 rpm, 21°C, for 10 min. The supernatant was removed and the pellet was washed with 500µL of phosphate buffer solution (PBS) and mixed well by vortexing for 3 min. About 1µL of this sample was spotted on the stainless steel MALDI target plate and overlaid with 1µL matrix solution (0.05 M Sinapinic acid in 3:1 Acetonitrile- water containing, 0.1% ) and air dried before the analysis by using MALDI-MS.

**Epifluorescence microscopic studies**

10µL of the bacterial cells incubated with the desired concentrations of CdS-MPA and CdSe-MUA QDs and the control were collected at incubation times of 3h and 12h and uniformly smeared using a sterile loop onto a clean glass slide and left to air dry in the laminar flow. The dry smears were flooded with acridine orange (0.1% solution in distilled water). After 2min, the excess stain was drained off and the glass slides were washed in sterile water, dried and observed. Acridine orange, a fluorescent dye, differentially stains single stranded RNA and double stranded DNA, fluorescing orange when intercalated with the former and green while complexing with the latter when observed under a ESPA FI40(NIB-100F, ESPA systems Co. Ltd., Taiwan) inverted Epifluorescence microscope (excitation filter BP 490; barrier filter O 515). Thus, the number of orange fluorescing cells depicts the actively metabolizing cells on the TBC's (Gopal J et al. 2011). Based on this technique it was possible to image the cells contained in 10µL of the solution following incubation with the two QDs.

**Result and discussion:**

**Characterization of QDs**

The size of the CdS-MPA QDs was confirmed by TEM Fig. 1 (a) and the average size was found to be around 5nm as shown in the size distribution histogram in Fig.1(b). Fig.1(c) reveals the appearance of the CdS QDs capped with MPA under normal light and under UV light, under UV light we can observe the fluorescence, typical of all QDs. The UV-visible absorption spectra of

CdS QDs capped with MPA show maximum absorption at 269nm (Fig.1(d)) and Fig.1(e) shows the fluorescence emission spectra of CdS-MPA with its maximum emission wavelength at 595nm.

The size of the CdSe-MUA QDs was further confirmed by TEM as shown in Fig. 2 (a) and the average size was found to be around 4nm as shown in the size distribution histogram in Fig.2(b). Fig.2(c) reveals the appearance of the CdSe QDs capped with MUA under normal light and under UV light, in this case too, the fluorescing ability of the QDs under UV light is evident. The UV-visible absorption spectra of CdSe QDs capped with MUA show maximum absorption at 275nm (Fig.1(d)) and Fig.1(e) shows the fluorescence emission spectra of CdS-MPA with its maximum emission wavelength at 575nm.

**Evaluating the Cytotoxicity of CdS-MPA and CdSe-MUA QDs using MALDI-MS**

First, MALDI-MS was done for optimization of the both the CdS-MPA QDs and CdSe-MUA QDs in minimum concentration to see the changes in the bacterial peaks. It was observed the same concentration range of both the QDs in Fig. SA1 and Fig. SA2 from (a) 0.00 mg/mL, (b) 0.01 mg/mL, (c) 0.02 mg/mL, (d) 0.04 mg/mL, (e) 0.05 mg/mL, (f) 0.1 mg/mL had no effect on the bacterial peaks. It shows there was no effect of toxicity on the bacterial cells which gave the permission to use higher concentration of both the QDs.

Fig 3A(a-f) are the spectra obtained from the *S.aureus* cells exposed to different concentration of CdS-MPA QDs. MALDI-MS spectra acquired after 3h incubation of *S.aureus* cells with 0.00mg/mL (Fig.3A(a)) 0.05mg/mL (Fig.3A(b)), 0.1mg/mL (Fig.3A(c)), 0.2mg/mL (Fig.3A(d)) 0.4mg/mL (Fig.3A(e)) and 0.5mg/mL (Fig.3A(f)) concentrations of CdS-MPA show no spectral changes at all concentrations. Even after a prolonged incubation period of 6h (Fig.S2A (a-f)) and 9h (Fig. S3A (a-f)), none of the concentrations showed any peak suppression, indicating that these QDs were highly biocompatible with *S.aureus* cells. It was interesting to observe that after a 12h incubation time, while CdS-MPA QDs concentrations of 0.05mg/mL (Fig.4A(b)), 0.1mg/mL (Fig.4A(c)), 0.2mg/mL Fig.4A(d)) 0.4mg/mL (Fig.4A(e)) still did not show any

evident peak inhibition, the highest concentration used, which was 0.5mg/mL (Fig.4A(f)) showed significant suppression of peaks. Thus, these results reveal that the CdS-MPA QDs are not entirely biocompatible, but do show some toxicity at concentrations > 0.5mg/mL after prolonged incubation (>12h).

However, in the case of the CdSe-MUA QDs (Fig. 3B(a-f)), even as early as 3h, we could observe the total suppression of the protein peaks, signifying that these QDs were highly toxic to the cells and lead to inhibition of protein peaks. Compared to the control (Fig.3B(a)), all concentration of CdSe-MUA including 0.05mg/mL (Fig.3B(b)), 0.1mg/mL (Fig.3B(c)), 0.2mg/mL (Fig.3B(d)) 0.4 mg/mL (Fig.3B(e)) and 0.5 mg/mL (Fig.3B(f)) were bactericidal. This trend continued at 6h incubation time (Fig. S2B(b-f), 9h (Fig. S3 (B(b-f)) and 12 h (Fig. 4B(b-f)) incubation time.

The cytotoxicity of Cd containing QDs is due to the releasing of $Cd^{2+}$ from the core[22]. The absorption of Cd from the QDs onto the cell wall triggers results in the oxidative damage[22-23]. The reactive oxygen species (ROS) is also responsible for the damage of bacterial cell walls[23]. The photoactivation process is also responsible for the damage of cells which was already known [24-25]. In the present study it was rather unique to observe that although both QDs contained Cd, their cytotoxic properties with respect to the model bacterium, *S.aureus* were distinctly different. The other interesting point that need to be emphasized is that, previous studies conducted in our laboratory using CdS–MPA QDs confirmed that they could degrade the extra polymeric substances (EPS) surrounding *E.coli* cells[19] and also around the yeast cells[26]. But, our studies indicate that the toxicity towards *S.aureus* was considerably different.

**Evaluating the Cytotoxicity of CdS-MPA and CdSe-MUA QDs using Epifluorescence technique**

After an incubation period of 3h, the bacterial smear was made and stained with AO and observed under the epifluorescence microscope. In Fig 5A (a-f) we can see the images of the *S.aureus* cells exposed to different concentrations of CdS-MPA QDs. As portrayed in the MALDI-MS results after a 3h incubation of *S.aureus* cells with 0.00mg/mL (Fig.5A(a)) 0.05mg/mL (Fig.5A(b)), 0.1mg/mL (Fig.5A(c)), 0.2mg/mL (Fig.5A(d)) 0.4mg/mL (Fig.5A(e)) and 0.5mg/mL (Fig.5A(f)) concentrations of CdS-MPA showed no significant reduction in the cells compared to the control (Fig. 5A(a)). Even after a prolonged incubation period of 12h (Fig.S4A (a-f)) the cell numbers in the smear were still high, this indicates that these QDs were

highly biocompatible with *S.aureus* cells. However, the CdSe-MUA QDs and their effect on the *S.aureus* cells were adverse and followed the same trend indicated in the MALDI-MS results (highly toxic even at low concentrations). After an incubation time of 3h, compared to the control (Fig.5B(a)), all concentration of CdSe-MUA including 0.05mg/mL (Fig.5B(b)), 0.1mg/mL (Fig.5B(c)), 0.2mg/mL (Fig.5B(d)), 0.4mg/mL (Fig.5B(e)) and 0.5mg/mL (Fig.5B(f)) were bactericidal as shown by the reduced fluorescing cells in the smear. Since the volume taken was the same, the reduced cell numbers indicate that the total density of the bacterial cells on exposure to the toxic QDs was less. This trend continued to 12h incubation time (Fig. S4B(b-f) too.

Thus, these results also confirm that the suppression in protein peaks during MALDI-MS analysis did reflect the suppression of the growth suppression or toxic effect reflected by the epifluorescence images as well. Changes in the spectra have been confirmed to indicate inhibition of growth and as an indicator of the cell death in our previous publications. Judy et al[20], report that the suppression of bacterial peaks, following incubation with ZnO NPs in a MALDI-MS spectra to be directly related to the live/dead state of the bacteria. Speculating the reason for the biocompatibility of the CdS- MPA QDs and the toxicity of the CdSe-MPA QDs, although we do not have direct and conclusive reasons[27] have shown that the cytotoxicity of QDs was not only determined by the physicochemical properties such as the capping agents but also related to different target cells. Hence, the trend observed above, is not generalized for all bacterial cells, but for S. aureus cells alone. Also Hanaki K[28] , confirm that the MUA capped QDs found no effect on cell viability as demonstrated by MTT assay. But according to Adam. L et.al 2009, their group evaluated this effect by using the ionic liquid of different alkyl chains and interact with green algae (*Chlorella vulgaris and Oocystis submarine*). They found, on increasing the length of alkyl chain it increases the toxicity in cells[29]. In our study we can also correlate this fact that MUA (mercapto undecanoic acid) 11 carbon compound had greater toxicity effect as compared to MPA (mercapto propionic acid) which is only 3 carbon compound.

Optical Density 600nm (O.D 600nm) was also measured for observing the light scattering by the microbes, which is directly proportional to cell density. 3mL of the bacterial suspension was taken in a cuvette and its O.D600 was measured. First optimization was checked for lower concentration of both the QDs with *S.aureus* from 0.00mg/mL, 0.01mg/mL, 0.02mg/mL, 0.03mg/mL, 0.04mg/mL and 0.05mg/mL. It was found that at these concentrations there was not great difference in the absorbance as shown in Fig. 6 (a). The relative change can be seen in the other histograms in Fig. 6 (b,c,d,e,) after 3,6,9 and 12 hrs respectively. Only in the last histogram

for 12 hrs decreased in absorbance can be noted for the 0.5mg/mL for the CdS-MPA QDs where as for the CdSe-MUA this change starts from 0.05mg/mL after 3 hrs. This shows duration and concentration dependent of biocompatibility of both QDs. There by it can be helpful in selecting the QDs for research and other purpose.

## Conclusion

CdS-MPA and CdSe-MUA QDs were incubated with *Staphylococcus aureus* to study their toxicity on these bacterial cells. The results confirmed by MALDI-MS, Epifluorescence technique as well as spectrophotometric results showed that CdS – MPA QDs were more biocompatible compared to CdSe - MUA capped QDs. The critical concentration for CdS – MPA QDs was 0.5mg/mL after 12 hrs and for CdSe - MUA capped QDs was 0.5mg/mL after 3 hrs.

## Acknowledgements

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**Figure Captions**

Fig 1. Characterization of CdS-MPA QDs (a) TEM (b) Histogram of particle distribution (c) Photograph taken on illumination with normal light and UV light. (d) UV absorption spectra (e) Fluorescence spectra.

Fig 2. Characterization of CdSe-MUA QDs (a) TEM (b) Histogram of particle distribution (c) Photograph taken on illumination with normal light and UV light (d) UV absorption spectra (e) Fluorescence spectra.

Fig 3A. MALDI-MS spectra acquired after a 3h incubation of *S.aureus* cells with (a) 0.00mg/mL, (b)0.05mg/mL, ( c) 0.1mg/mL, (d) 0.2mg/mL, (e) 0.4mg/mL and (f) 0.5 mg/mL concentrations of CdS-MPA.

Fig 3B. MALDI-MS spectra acquired after a 3h incubation of *S.aureus* cells with (a) 0.00mg/mL, (b)0.05mg/mL, ( c) 0.1mg/mL, (d) 0.2mg/mL, (e) 0.4mg/mL and (f) 0.5 mg/mL concentrations of CdSe-MUA .

Fig 4A. MALDI-MS spectra acquired after a 12h incubation of *S.aureus* cells with (a) 0.00mg/mL, (b) 0.005mg/mL, ( c) 0.1mg/mL, (d) 0.2mg/mL, (e) 0.4mg/mL and (f) 0.5mg/mL concentrations of CdS-MPA

Fig 4B. MALDI-MS spectra acquired after a 12h incubation of *S.aureus* cells with (a) 0.00mg/mL, (b) 0.05mg/mL, ( c) 0.1mg/mL, (d) 0.2mg/mL, (e) 0.4mg/mL and (f) 0.5mg/mL concentrations of CdSe-MUA

Fig. 5A. Epifluorescence micrographs of *S.aureus* cells incubated with (a) 0.00mg/mL, (b) 0.05mg/mL, ( c) 0.1mg/mL, (d) 0.2mg/mL, (e) 0.4mg/mL and (f) 0.5mg/mL concentrations of CdS-MPA for 3h

Fig. 5B. Epifluorescence micrographs of *S.aureus* cells incubated with (a) 0.00mg/mL, (b) 0.05mg/mL, ( c) 0.1mg/mL, (d) 0.2mg/mL, (e) 0.4mg/mL and (f) 0.5mg/mL concentrations of CdSe-MUA for 3 h.

Fig. 6 O.D600nm response of S. *aureus* by CdS-MPA and CdSe-MUA QDs. (a) Optimization of concentration of both QDs. (b) After 3hr of incubation (c) After 6hr of incubation (d) After 9hr of incubation (e) After 12hr of incubation

# Figure captions

**Fig 1**. Characterization of CdS-MPA QDs (a) TEM (b) Histogram of particle distribution (c) Image taken by Camera under normal light and UV light. (d) UV absorption at 270nm (e) Fluorescence emission.

**Fig 2**. Characterization of CdSe-MUA QDs (a) TEM (b) Histogram of particle distribution (c) Image taken by Camera under normal light and UV light. (d) UV absorption at 280nm (e) Fluorescence emission.

**Fig 3A**. MALDI-MS spectra acquired after a 3h incubation of *S.aureus* cells with (a) 0.00mg/mL, (b)0.05mg/mL, ( c) 0.1mg/mL, (d) 0.2mg/mL, (e) 0.4mg/mL and (f) 0.5 mg/mL concentrations of CdS-MPA.

**Fig 3B**. MALDI-MS spectra acquired after a 3h incubation of *S.aureus* cells with (a) 0.00mg/mL, (b)0.05mg/mL, ( c) 0.1mg/mL, (d) 0.2mg/mL, (e) 0.4mg/mL and (f) 0.5 mg/mL concentrations of CdSe-MUA .

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**Fig 4B**. MALDI-MS spectra after a 12h incubation of *S.aureus* cells with (a) 0.00mg/mL, (b) 0.05mg/mL, ( c) 0.1mg/mL, (d) 0.2mg/mL, (e) 0.4mg/mL and (f) 0.5mg/mL concentrations of CdSe-MUA

**Fig. 5A**. Epifluorescence micrographs of *S.aureus* cells incubated with (a) 0.00mg/mL, (b) 0.05mg/mL, ( c) 0.1mg/mL, (d) 0.2mg/mL, (e) 0.4mg/mL and (f) 0.5mg/mL concentrations of CdS-MPA for 3h

**Fig. 5B**. Epifluorescence micrographs of *S.aureus* cells incubated with (a) 0.00mg/mL, (b) 0.05mg/mL, ( c) 0.1mg/mL, (d) 0.2mg/mL, (e) 0.4mg/mL and (f) 0.5mg/mL concentrations of CdSe-MUA for 3 h.

**Fig. 6** O.D600nm response of S. *aureus* by CdS-MPA and CdSe-MUA QDs. (a) Optimization of concentration of QDs. (b) After 3hr of incubation (c) After 6hr of incubation (d) After 9hr of incubation (e) After 12hr of incubation.

# Supporting figure captions

**Fig S1.**Schematic showing flow of methods used in this experiment.

**Fig S1.(A**) MALDI-MS spectra acquired after a 3h incubation of *S.aureus* cells with a) 0.00mg/mL, (b) 0.01mg/mL, ( c) 0.02mg/mL, (d) 0.04mg/mL, (e) 0.05mg/mL and (f) 0.1mg/mL concentrations of CdS-MPA (B) MALDI-MS spectra acquired after a 3h incubation of *S.aureus* cells with a) 0.00mg/mL, (b) 0.01mg/mL, ( c) 0.02mg/mL, (d) 0.04mg/mL, (e) 0.05mg/mL and (f) 0.1mg/mL concentrations of CdSe-MUA.

**Fig S2.(A)** MALDI-MS spectra acquired after a 6h incubation of *S.aureus* cells with a) 0.00mg/mL, (b) 0.05mg/mL, ( c) 0.1mg/mL, (d) 0.2mg/mL, (e) 0.4mg/mL and (f) 0.5mg/mL concentrations of CdS-MPA.

**Fig S2.(B**) MALDI-MS spectra acquired after a 6h incubation of *S.aureus* cells with a) 0.00mg/mL, (b) 0.05mg/mL, ( c) 0.1mg/mL, (d) 0.2mg/mL, (e) 0.4mg/mL and (f) 0.5mg/mL concentrations of CdSe-MUA.

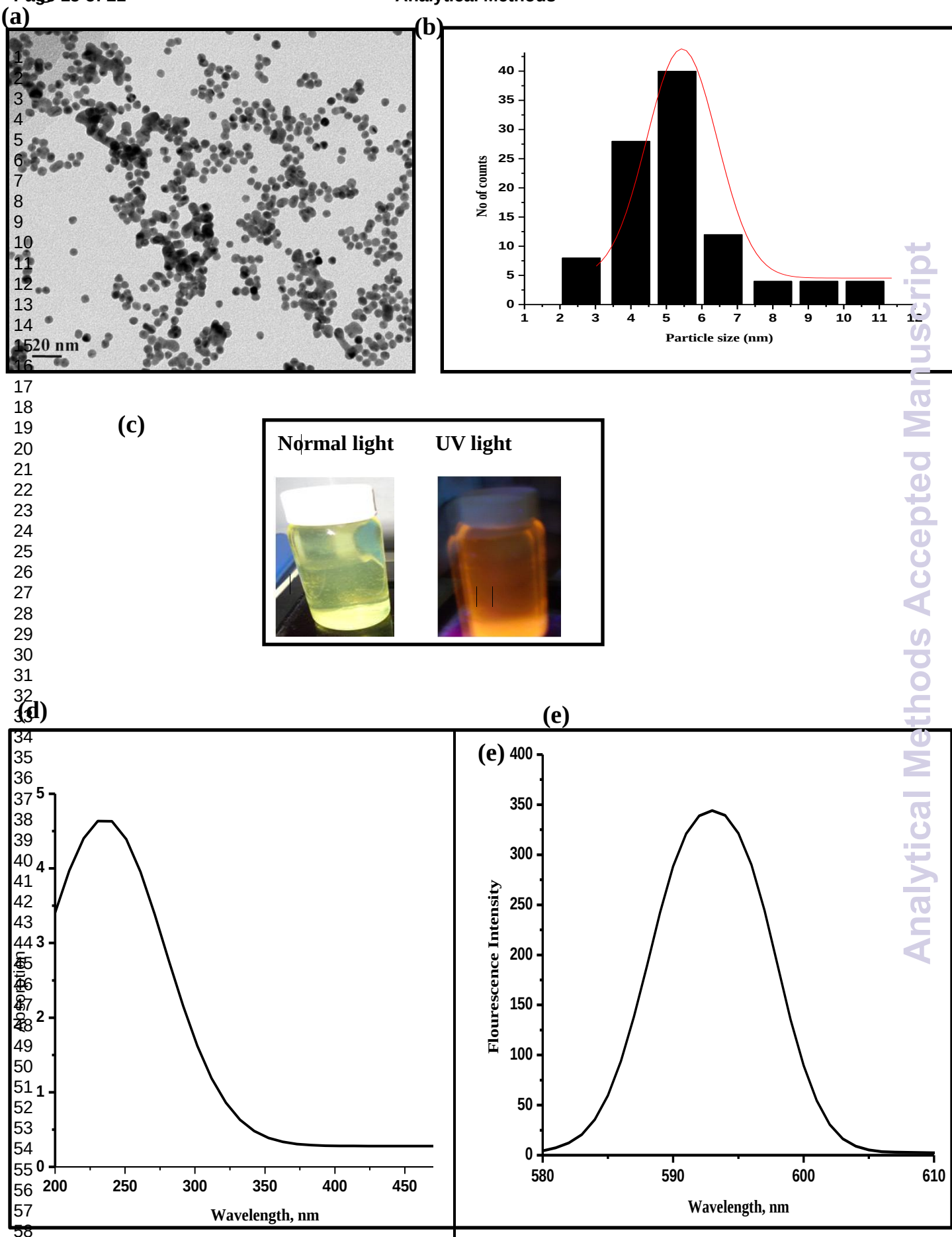
**Fig S3.(A)** MALDI-MS spectra acquired after a 9h incubation of *S.aureus* cells with a) 0.00mg/mL, (b) 0.05mg/mL, ( c) 0.1mg/mL, (d) 0.2mg/mL, (e) 0.4mg/mL and (f) 0.5mg/mL concentrations of CdS-MPA.

**Fig S3.(B)** MALDI-MS spectra acquired after a 9h incubation of *S.aureus* cells with a) 0.00mg/mL, (b) 0.05mg/mL, ( c) 0.1mg/mL, (d) 0.2mg/mL, (e) 0.4mg/mL and (f) 0.5mg/mL concentrations of CdSe-MUA.

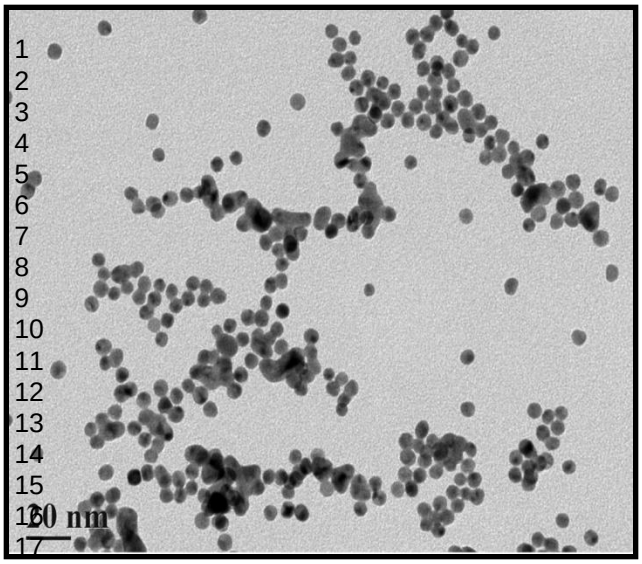
**Fig S4.(A)** Epifluorescence micrographs of *S.aureus* cells incubated with a) 0.00mg/mL, (b) 0.05mg/mL, ( c) 0.1mg/mL, (d) 0.2mg/mL, (e) 0.4mg/mL and (f) 0.5mg/mL concentrations of CdS-MPA for 12h.

**Fig S4.(B)** Epifluorescence micrographs of *S.aureus* cells incubated with a) 0.00mg/mL, (b) 0.05mg/mL, ( c) 0.1mg/mL, (d) 0.2mg/mL, (e) 0.4mg/mL and (f) 0.5mg/mL concentrations of CdSe-MUA for 12 h.

Fig. 1



(a)

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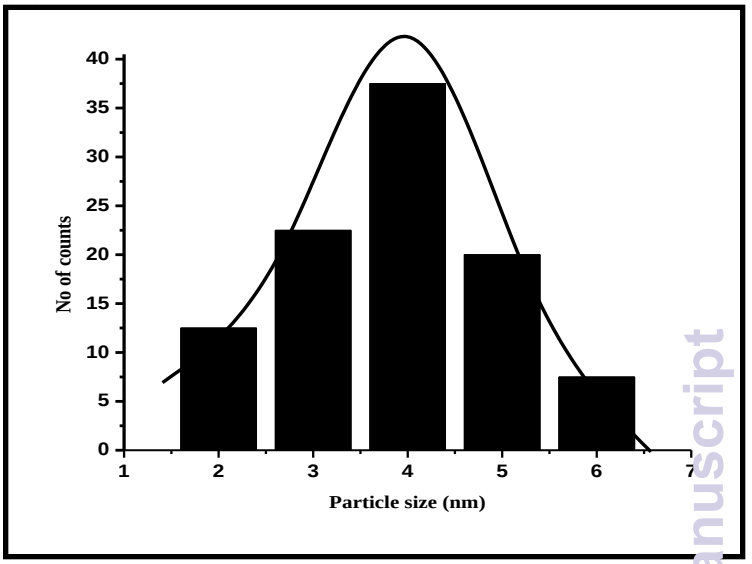


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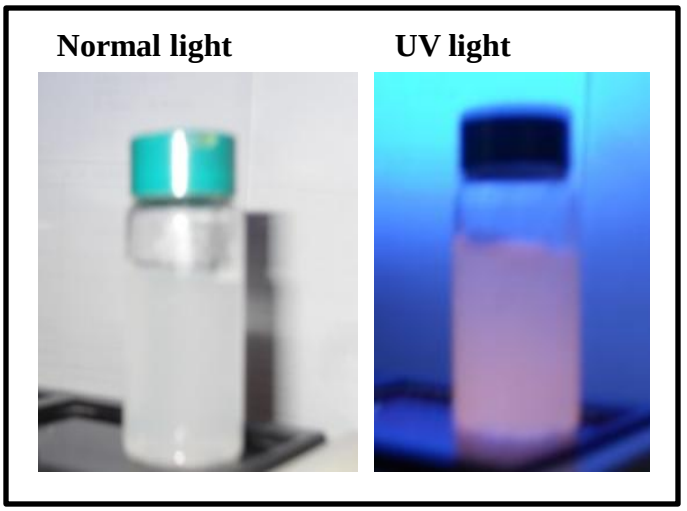


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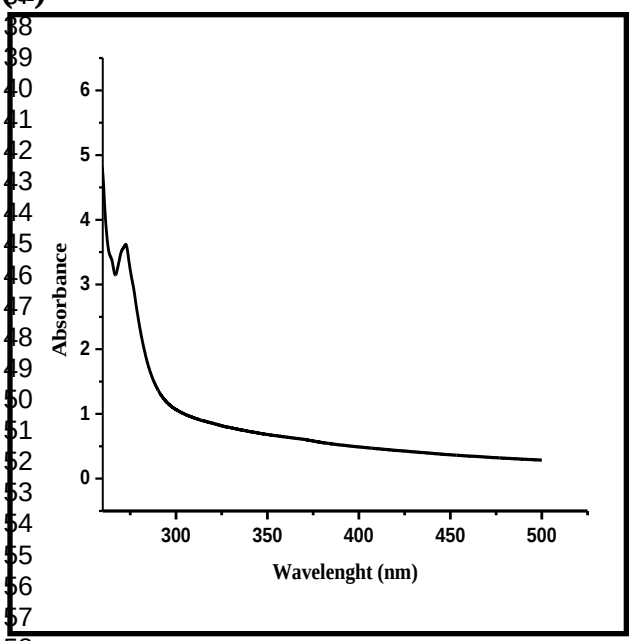


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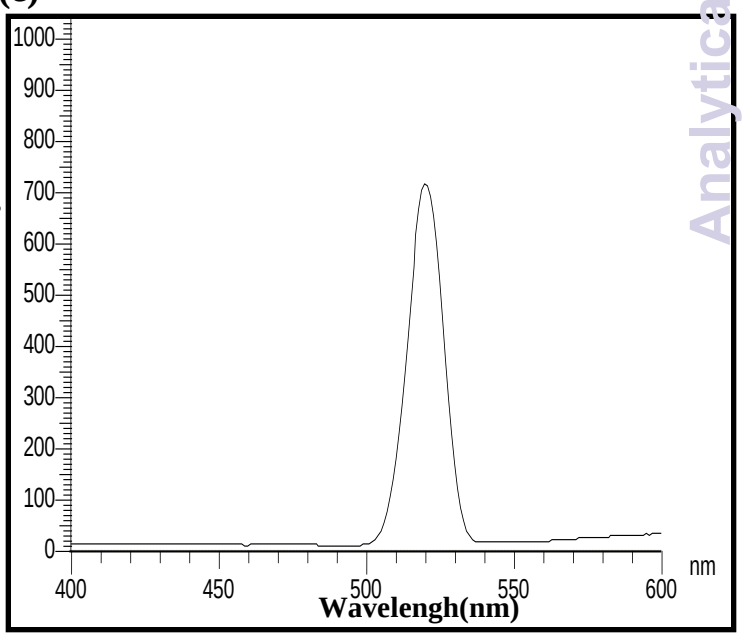

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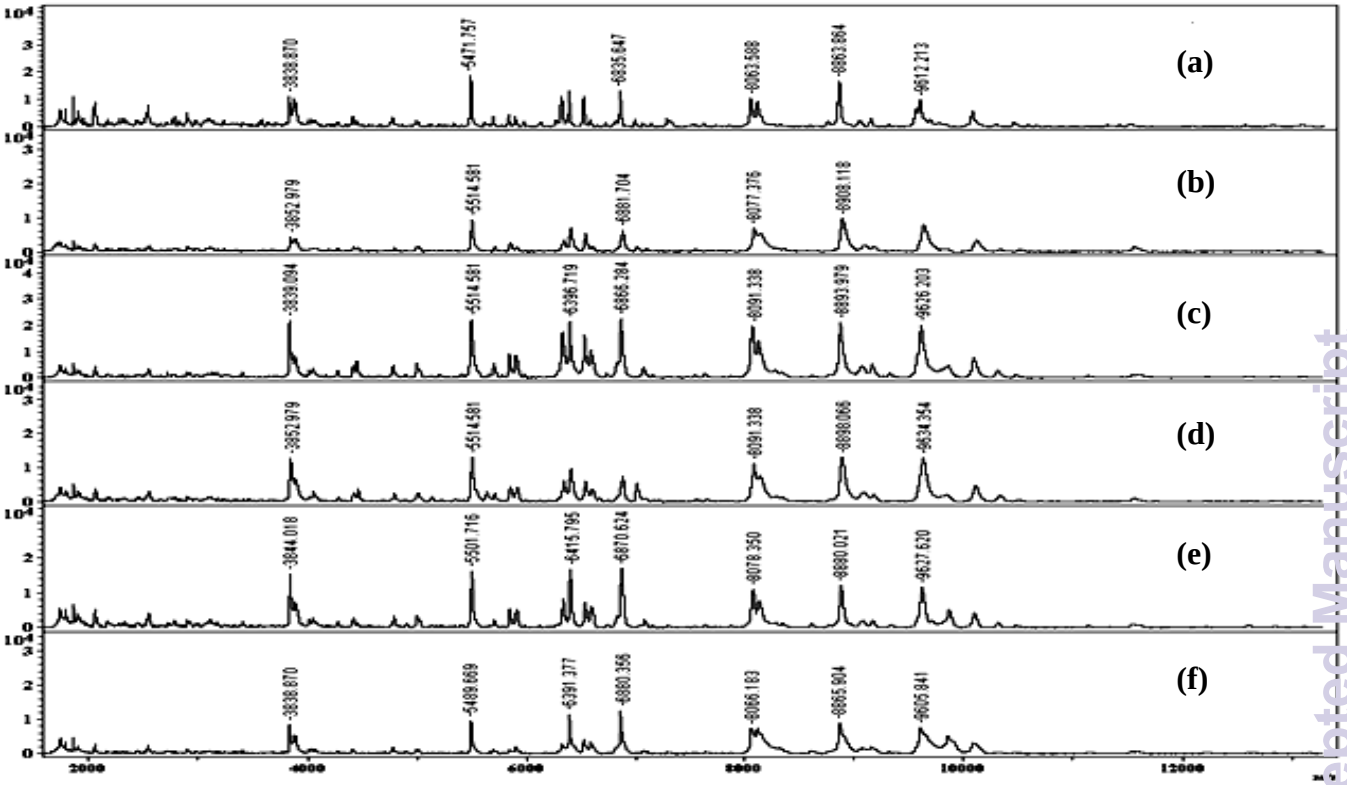
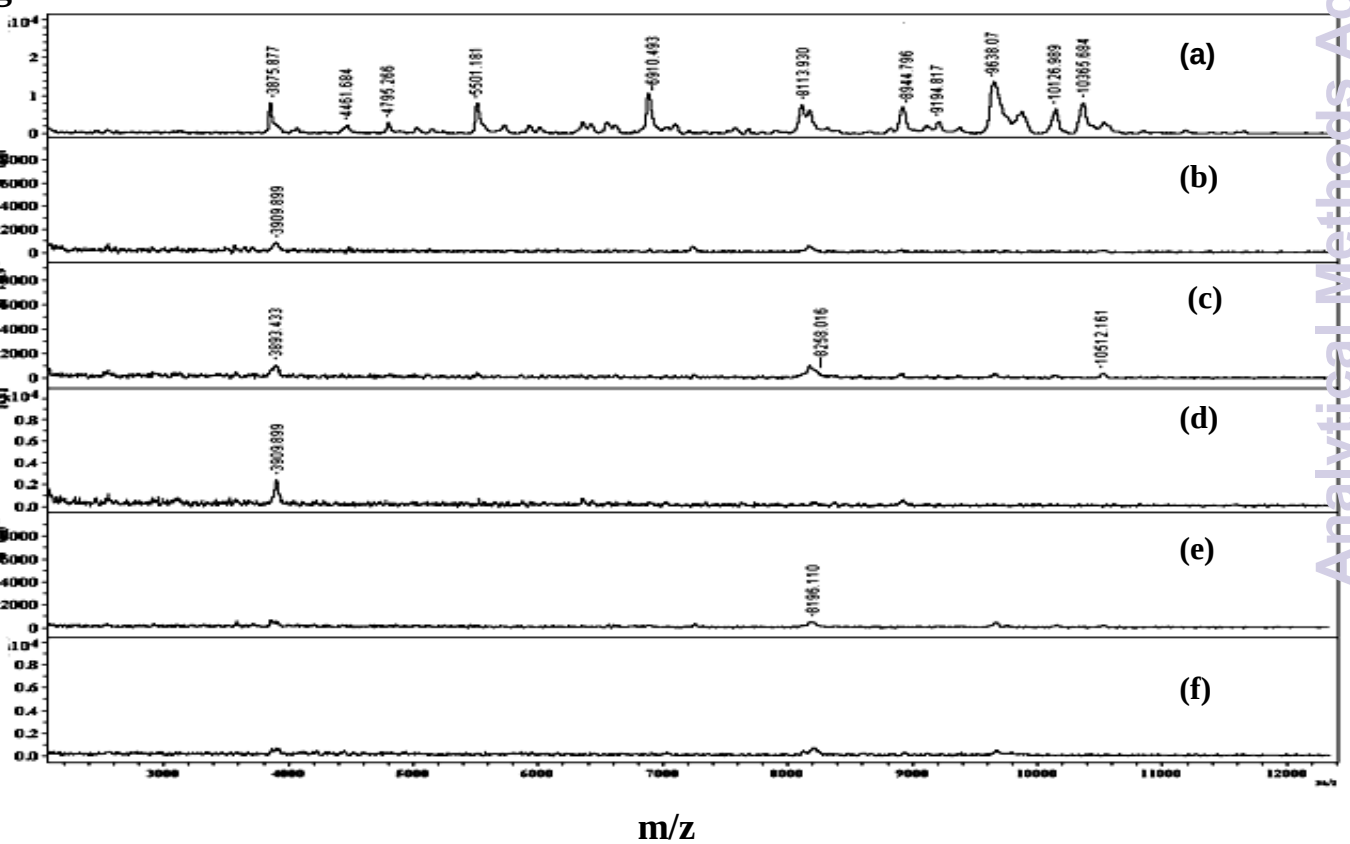



**Fig 3 B.**



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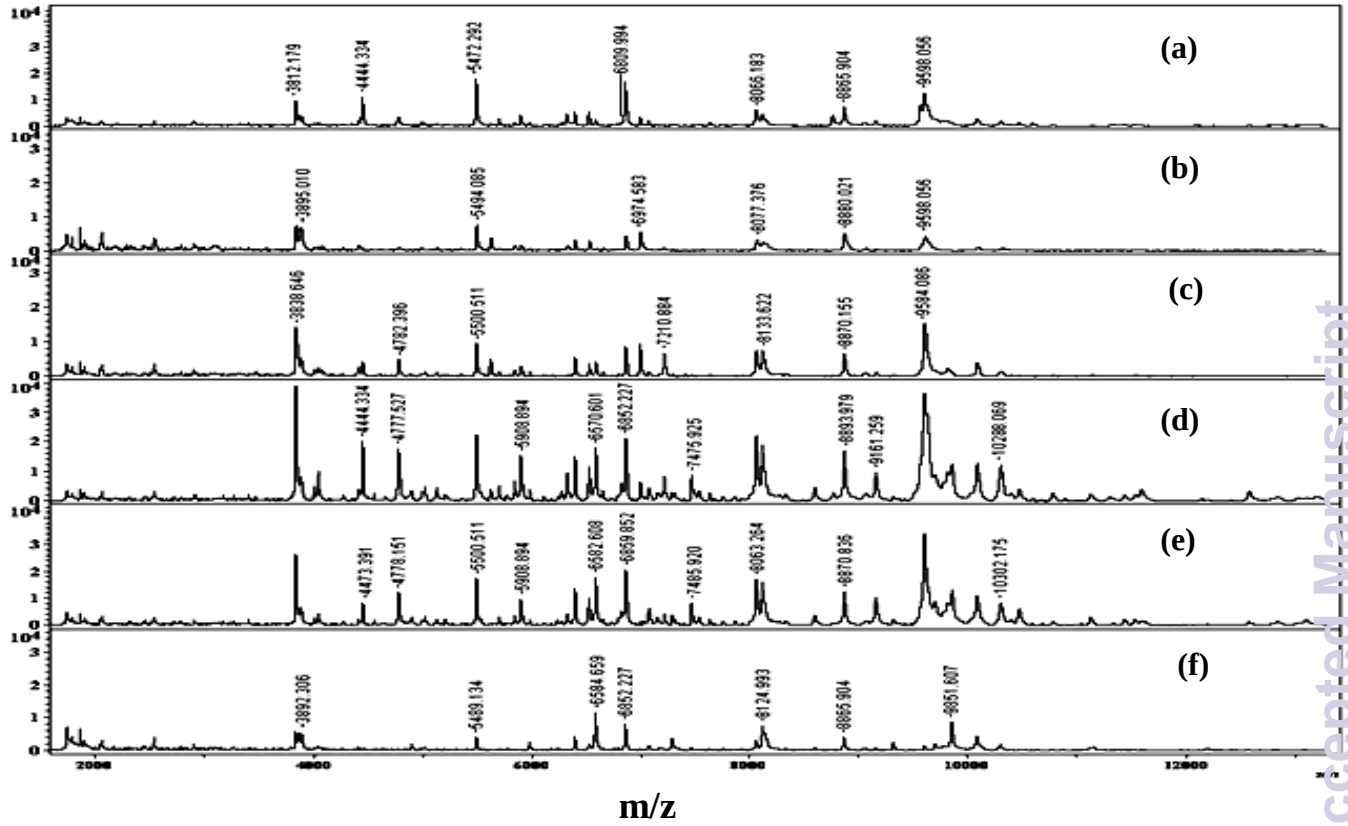


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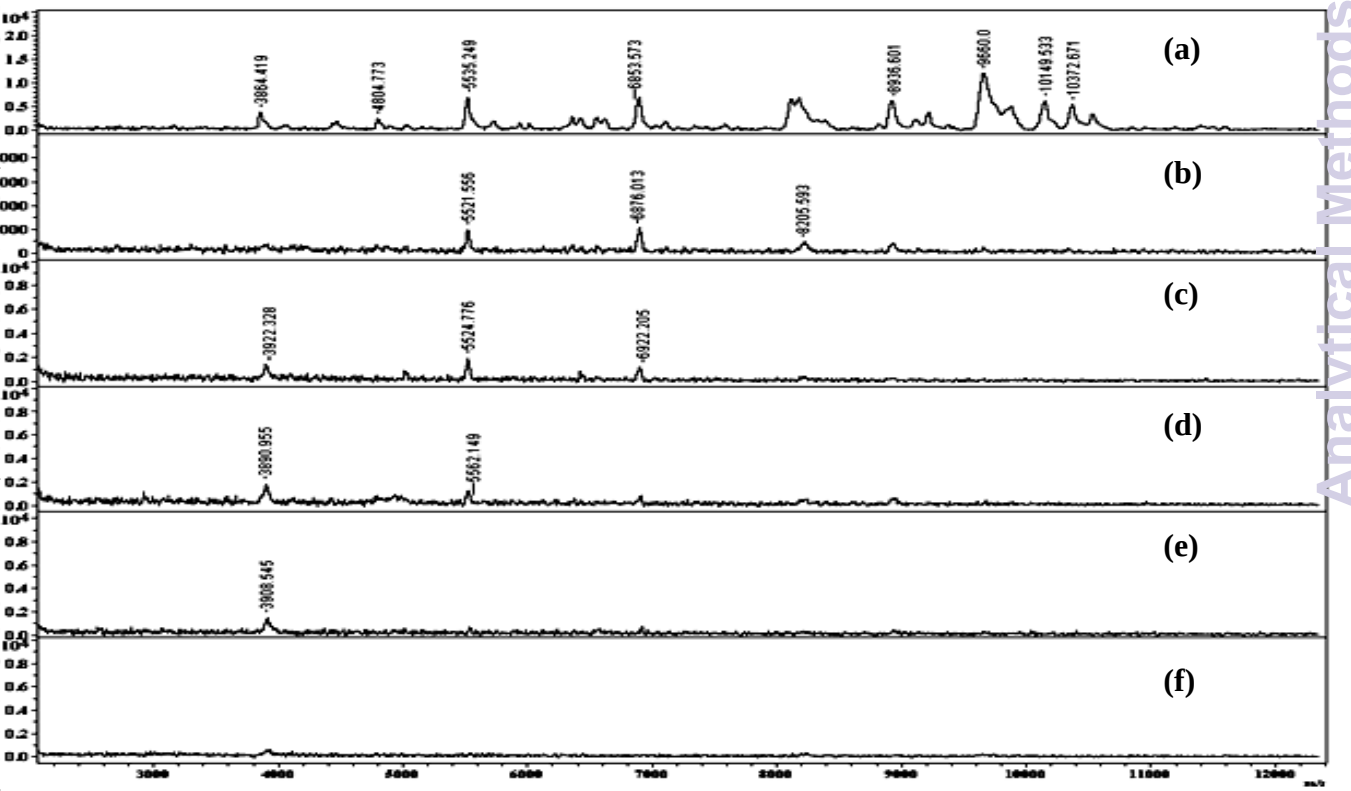


Fig 5 A

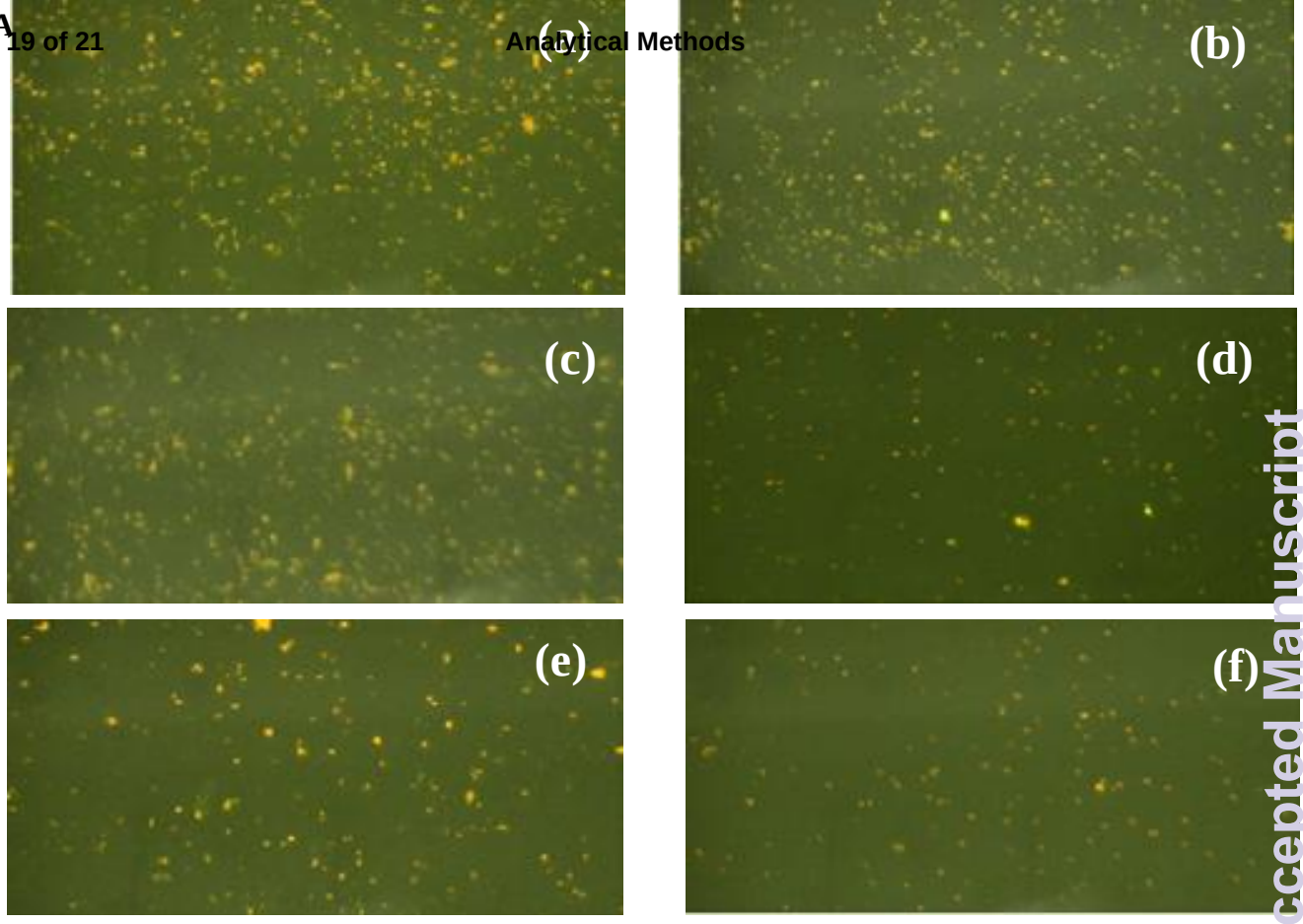



Fig 5 B.

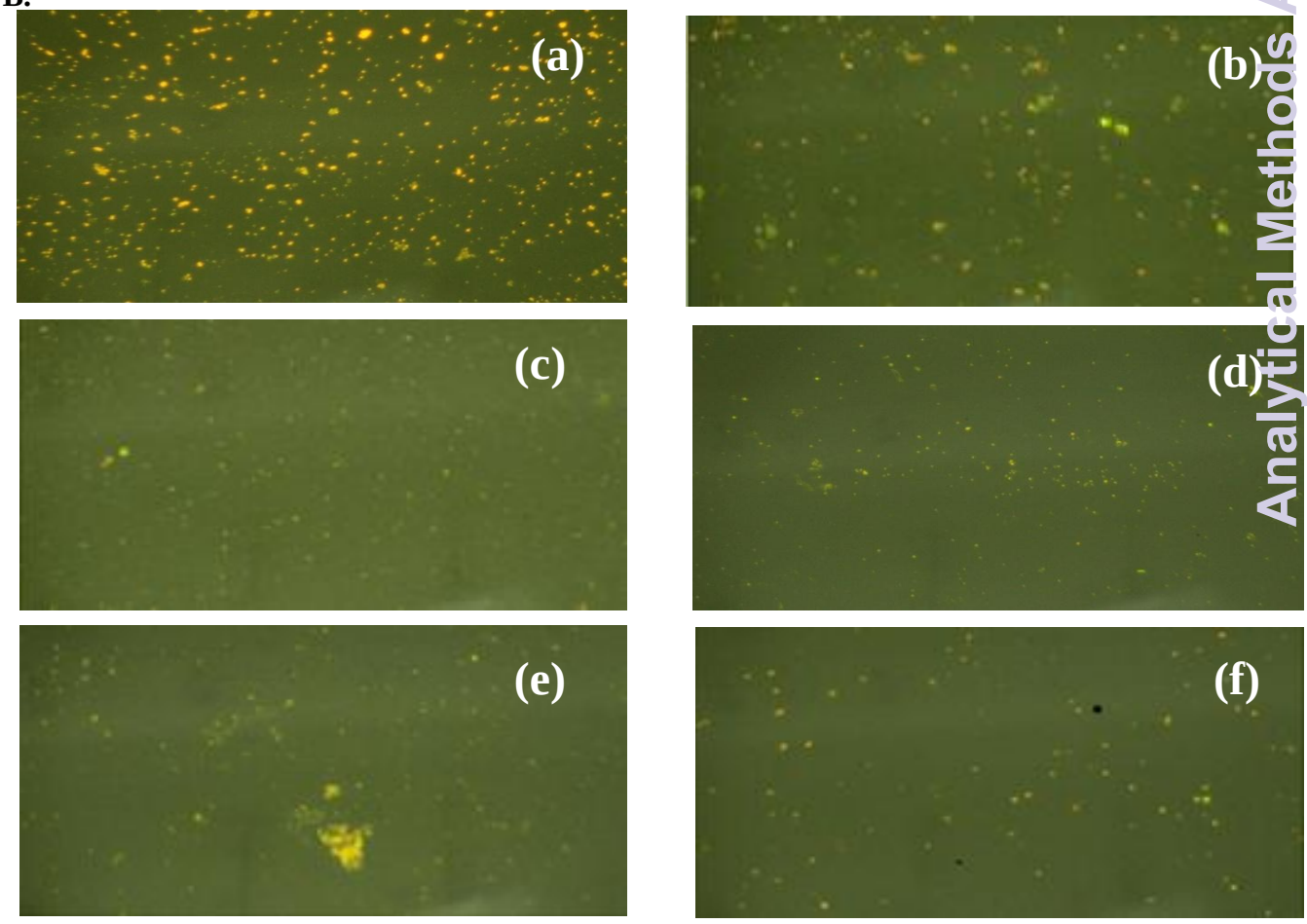
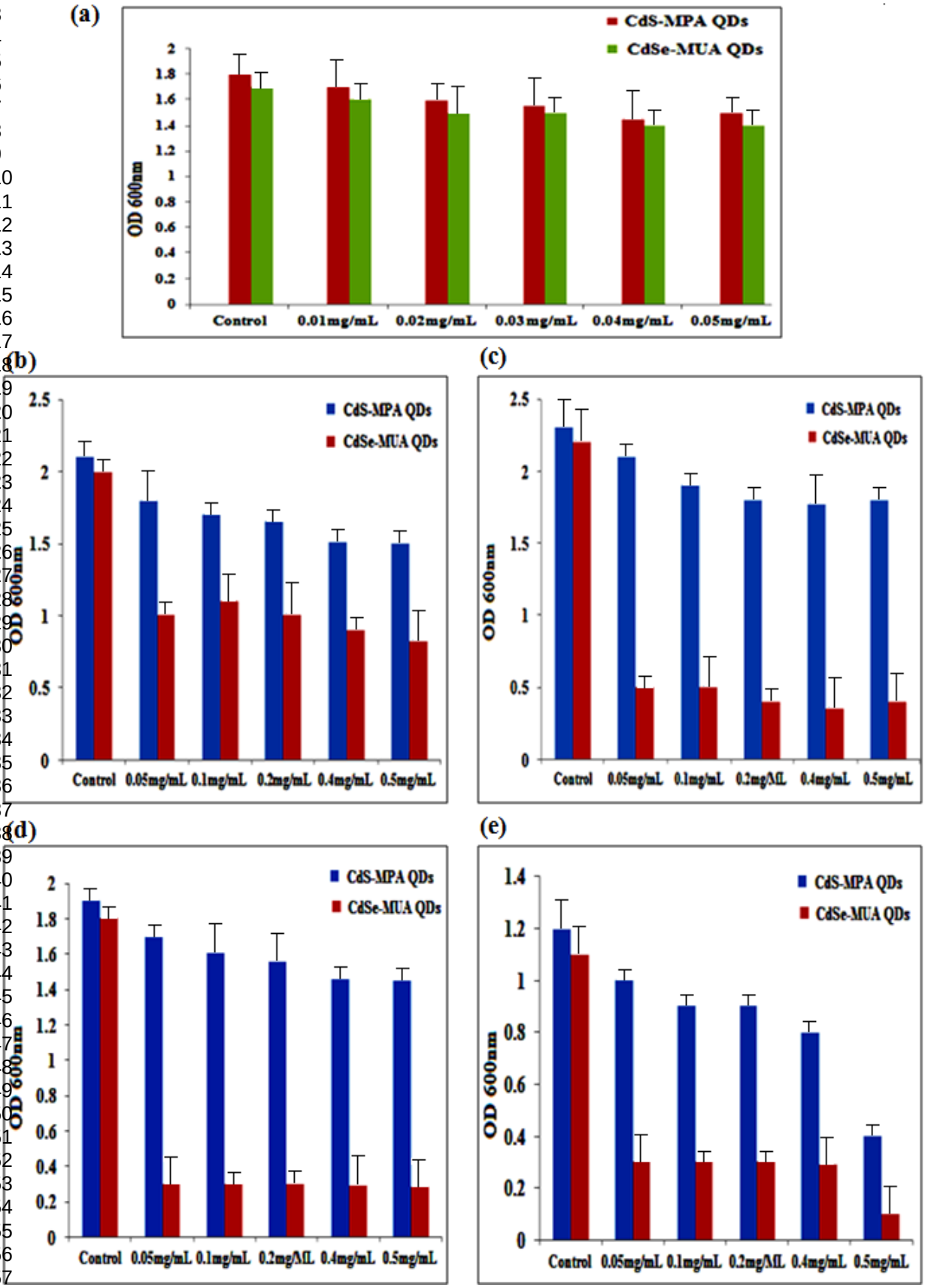
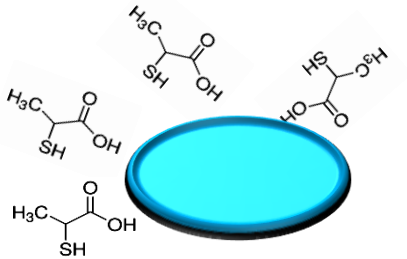


Fig.6



# Graphical Abstract

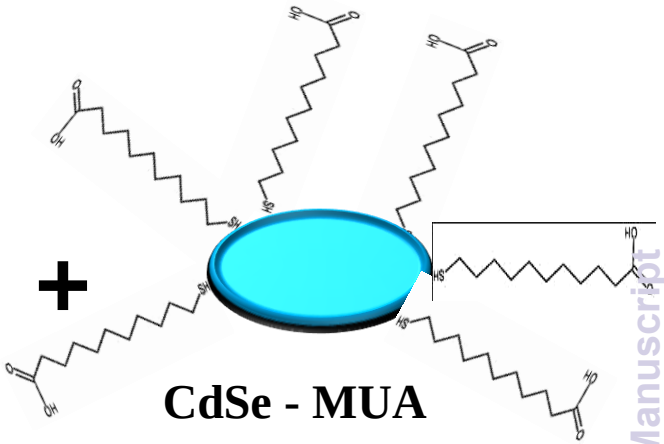


CdS - MPA

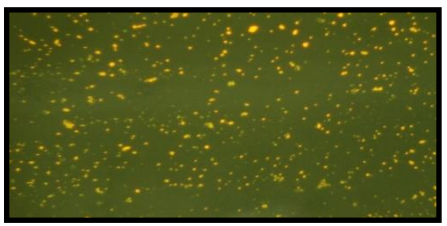
+

*Staphylococcus aureus*

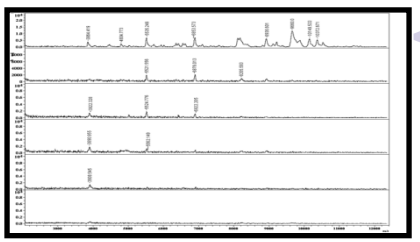
+



CdSe - MUA



Epifluorescence micrographs



MALDI-MS spectra