[Electronic Supporting Information]

Highly Efficient Energy Transfer from Water Soluble Zinc Silver Indium Sulphide Quantum Dot to Organic J-Aggregates

Naupada Preeyanka,[a] Himani Dey,[a] Sudipta Seth,[b] Abdur Rahaman[a] and Moloy Sarkar [a] *

[a]*School of Chemical Sciences, National Institute of Science Education and Research, HBNI, P.O. Jatni, Khurda 752050, Bhubaneswar, Odisha, India*

[b]*Current Address: Division of Chemical Physics, Chemical Centre, Lund University, Box-124, Se-22100, Lund, Sweden.*

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*Corresponding author, Tel: +91-674-2494190 Fax:+91-674-2494004. Email: msarkar@niser.ac.in

Synthesis of Fluorescent ZAIS QDs

1 ml of 0.05 M $Zn(Ac)_2$ solution, 0.2 ml of 0.05 M $AgNO_3$ solution, 2 ml of 0.05 M In $(Ac)_3$ solution and 5 ml of 0.2 M GSH are introduced into a three neck flask. The pH of the solution is adjusted to 8.5. Then freshly prepared thioacetamide solution was injected into the above flask and total volume of the solution was adjusted to 50 ml. Finally, the resulting mixture was heated to 100^0C and refluxed for 4 hours. ZAIS QDs were separated by ethanol addition and centrifugation, and then dried under vacuum to prepare QD powder.

Synthesis of dye aggregate

The dye solution is prepared of concentration 5 x 10^{-4} M using Millipore water. In order to form aggregates, small amount of potassium chloride is added to the diluted stock solution of the dye.

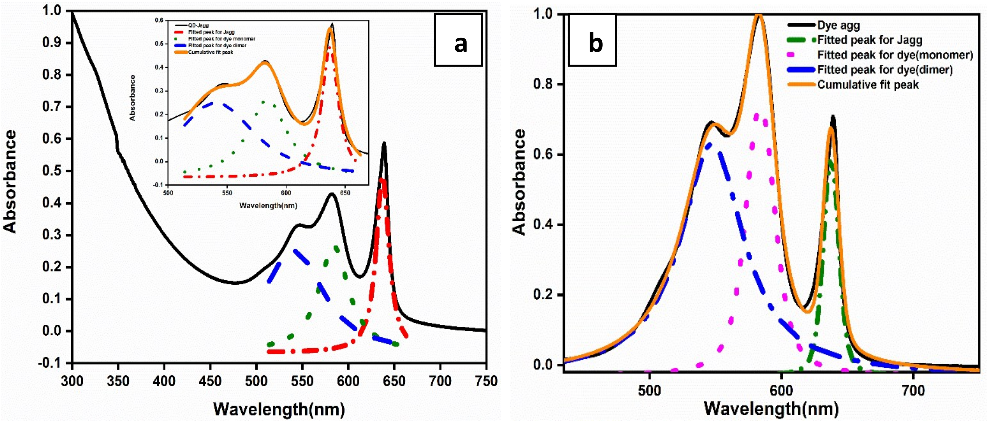

Fig. S1: Absorption spectra of a) dye aggregate and b) QD-J aggregate which is deconvoluted by multiple fit analysis.

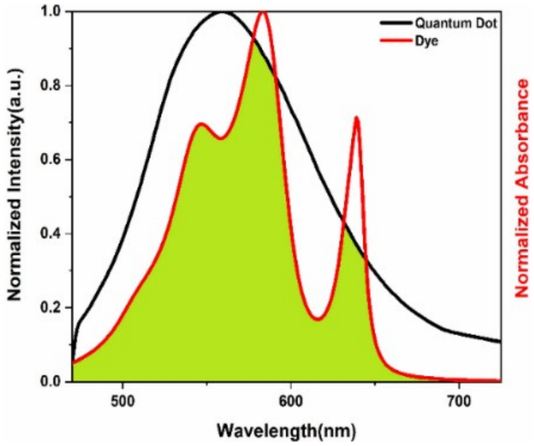

Fig. S2. Spectral overlap between the emission spectrum of QD and absorption spectrum of dye aggregate.

Explanation to rule out other charge transfer process

Two set of solutions were prepared. In one, only dye aggregate is present and in another set QD+dye aggregate is present. In later set, the dye was added to the QD solution with the same amount as in first set such that the concentration of dye is kept constant. The excitation is done at that wavelength where only QD absorbs i.e. 405 nm. And when we subtract the later from former, it has been observed that in the steady state emission spectra, with gradual addition of dye there is still an increase in the intensity of acceptor. The increase in acceptor emission is observed to be genuine and not due to the increase in OD of the acceptor moiety. This increase can be attributed to the fact that energy is being transferred from QD to dye aggregate though only QDs got excited. If electron charge transfer would have occurred then there should be no change in the intensity of dye aggregate with its gradual addition.

Stretched Exponential Fitting

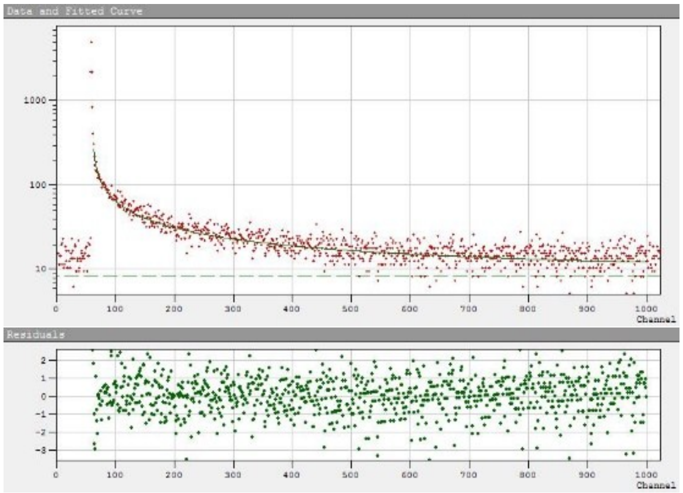

Fig. S3: Stretched exponential fitting of QD-dye aggregate hybrid system with the residual.

Construction of Time resolved emission spectrum (TRES) of ZAIS QDs and dye aggregate

a) Fluorescence lifetime decays of ZAIS QDs in aqueous medium is measured over the entire range of emission spectrum (570nm-750 nm) at 15 nm interval.

b) Deconvolution of the fluorescence decay at each wavelength is done using instrument response function and a multiexponential function, $(t) = \Sigma\alpha_i exp(-{}^{t}/_{\tau_i})$, i =1-4 by standard method of nonlinear least-squares and iterative reconvolution. As priority is to obtain noise free representation of intensity decay function, amplitudes and lifetimes in the fit have no physical meaning.

c) Time-resolved emission spectra (TRES) is plotted with intensity versus wavenumber. The equation used is

$$I(\upsilon,t) = I_{ss}(\upsilon)\frac{\Sigma_j\alpha_j(\upsilon)e^{-{}^{t}/_{\tau_j(\upsilon)}}}{\Sigma_j\,\alpha_j(\upsilon)\,\tau_j\,(\upsilon)}$$

Where $I_{ss}(\upsilon)$ is the steady state fluorescence intensity at υ and $\alpha_j(\upsilon)$ and $\tau_j\,(\upsilon)$ are the values of fit parameters.

d) TRANES is constructed using by normalizing the area of each spectrum in TRES.

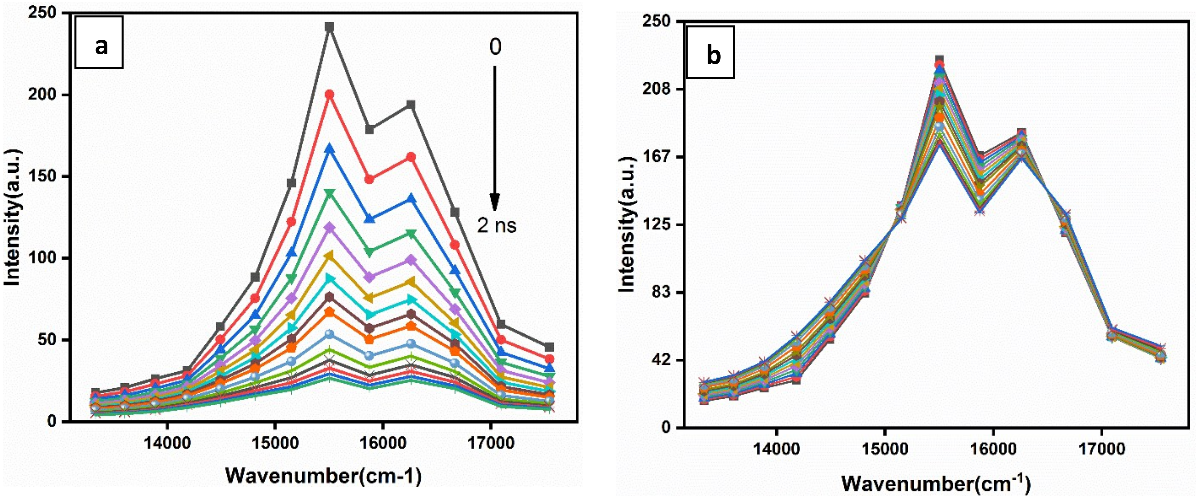

Fig. S4: TRES (a) and TRANES (b) of inorganic – organic hybrid conjugate showing multiple emitting species.

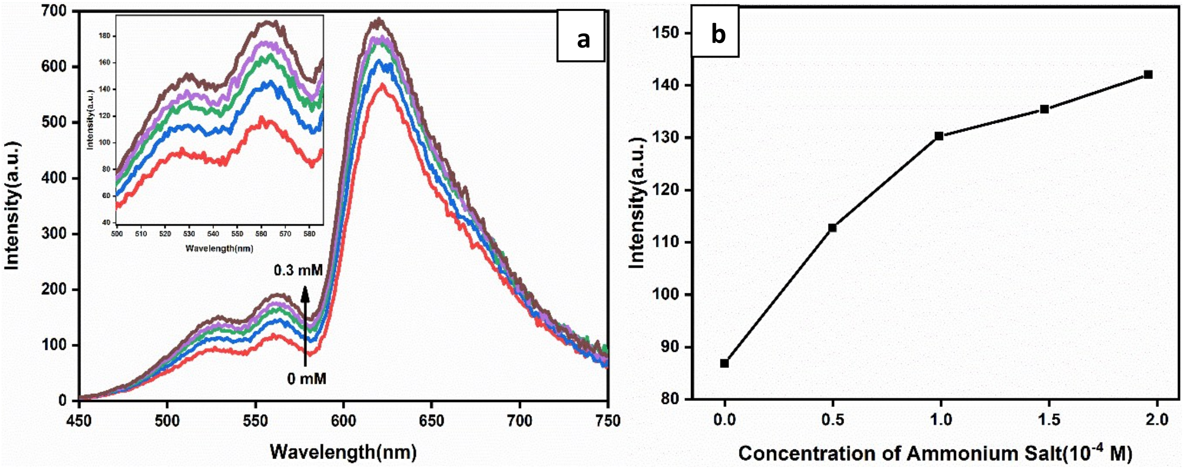

Fig. S5: a) The emission spectrum of gradual addition of tetraethyl ammonium perchlorate solution (10^{-2} M) to the QD-dye hybrid system. b) The plot showing the increase in PL intensity with the increase in concentration of the ammonium salt solution.

Stern-Volmer Analysis

The Stern-Volmer equation is given as

$$\frac{F_0}{F} = 1 + Ksv[Q]$$

where F_0 and F are fluorescence intensities of QDs in absence and presence of dye (quencher) respectively, Ksv is the Stern -Volmer constant which is estimated to be 1.29 x 10^5 M^{-1}. The linearity of Stern-Volmer plot in the Fig. S6 suggests the possibility of pure static or dynamic quenching. However, the decrease in slope of $\frac{F_0}{F}$ versus [Q] plot with increase in temperature indicates that static quenching prevails during the quenching event.

Biological Studies

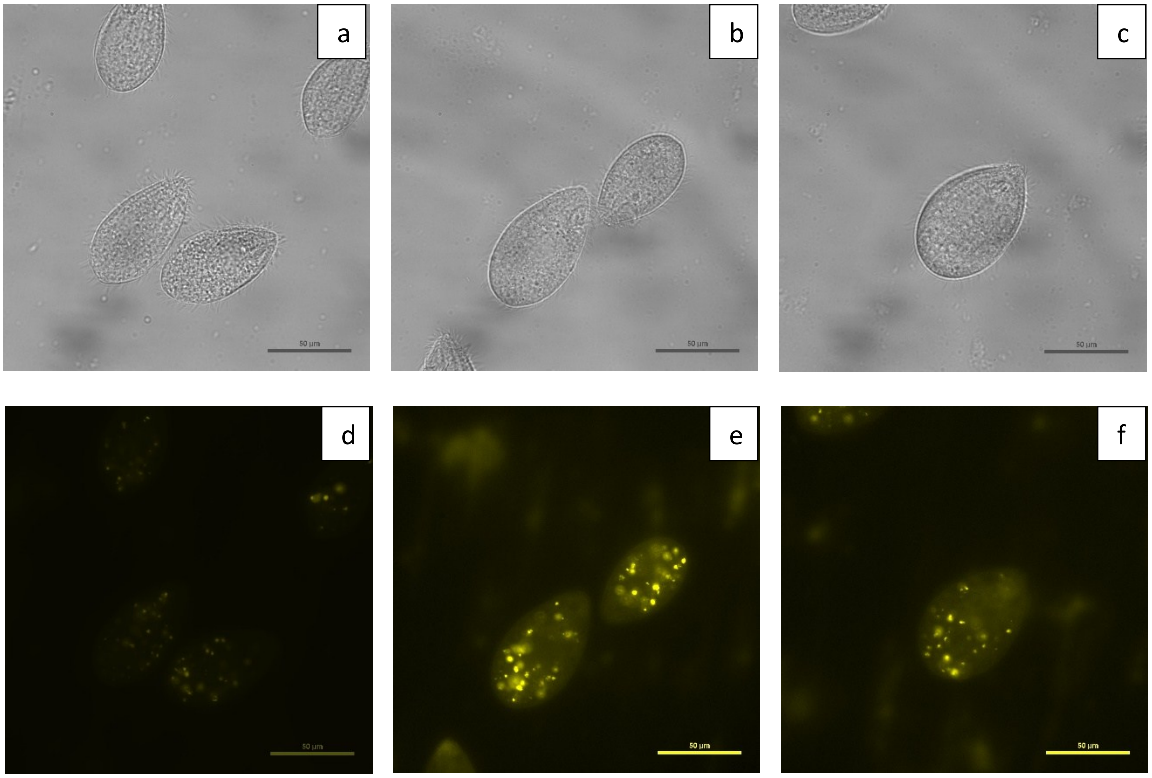

Fig. S6. DIC microscopic images of tetrahymena thermophila cells at 2 and 10 hours respectively (a,b,) after starvation. Fluorescence microscopic images at 2 hour and 10 hour (d,e) after starvation. (c,f) DIC and Fluorescence microscopic images after 10 minutes of removal of ZAIS QDs from media.

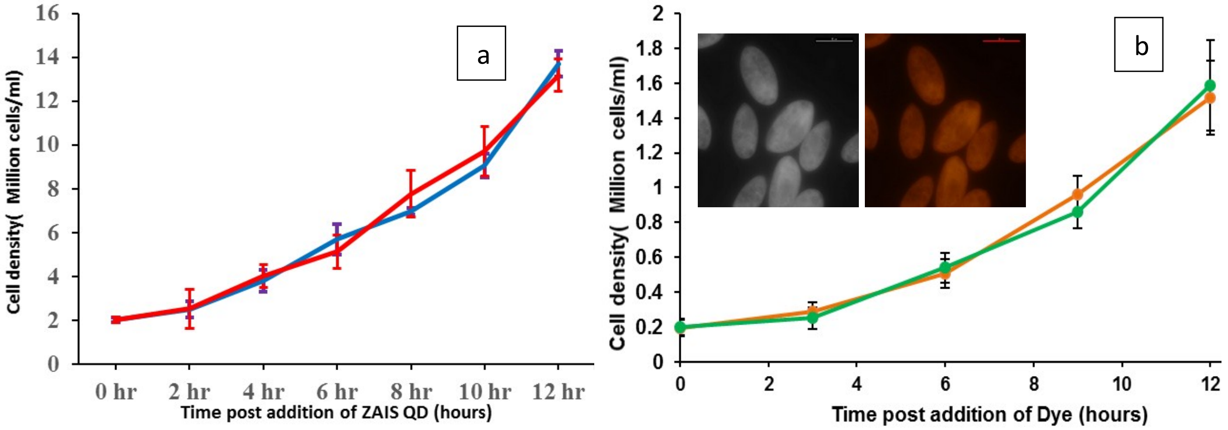

Fig. S7. Growth curve showing the effect of a) ZAIS QDs and b) Dye on Tetrahymena thermophila growth. (Inset of S8b is the DIC and fluorescence image of dye molecules.)

Table S1. Growth of tetrahymena thermophila cells in absence and presence of a) ZAIS QDs and b) Dye.

a

Time (hours)	Untreated	Treated
0	2.03	2.03
2	2.51	2.53
4	3.83	4.01
6	5.70	5.15
8	6.99	7.77
10	9.07	9.72
12	13.70	13.20

b

Time (hours)	Untreated	Treated
0	0.2	0.19
3	0.25	0.29
6	0.54	0.51
9	0.86	0.96
12	1.59	1.52