Electronic Supplementary Material (ESI) for Journal of Materials Chemistry B.

Supporting Information

Synthesis and Characterisation of Biocompatible Organic-Inorganic Core-Shell Nanocomposite Particles based on Ureasils

Ilaria Meazzini,[a,b,†] *Steve Comby,*[b,†] *Kieran D. Richards*[a], *Aimee M. Withers*[c], *François-Xavier Turquet,*[b,‡] *Judith E. Houston*[b, §¶], *Róisín M. Owens*[c] *and Rachel C. Evans*[a*]

[a] Department of Materials Science & Metallurgy, University of Cambridge, 27 Charles Babbage Road, CB3 0FS, U.K.

[b] School of Chemistry & CRANN Trinity College Dublin, Dublin 2, Ireland

[c] Department of Chemical Engineering & Biotechnology, University of Cambridge, Philippa Fawcett Drive, Cambridge, CB3 0AS, UK.

[†] These authors contributed equally to this work.

[‡] Present address: Laboratoire de Chimie, ENS Lyon, 46, allée d'Italie, 69364 LYON CEDEX 07, France

[§] Present address: European Spallation Source ERIC, Box 176, SE-221 00 Lund, Sweden.

* Corresponding Author: rce26@cam.ac.uk

TABLE OF CONTENTS

1 Characterization of d-UPTES intermediate

Formation of the d-ureapropyltriethoxysilane (d-UPTES) intermediate was confirmed by Fourier Transform infrared (FTIR) spectroscopy, see Figure S1. The formation of urea linkages between 3-isocyanatopropyltriethoxysilane (ICPTES) and Jeffamine ED-600 results in disappearance of the strong vibrational band corresponding to the isocyanate moieties (2265 cm^{-1}) and the appearance of the features characteristic of urea groups (*e.g.* C=O stretch centred at 1635 cm^{-1}).

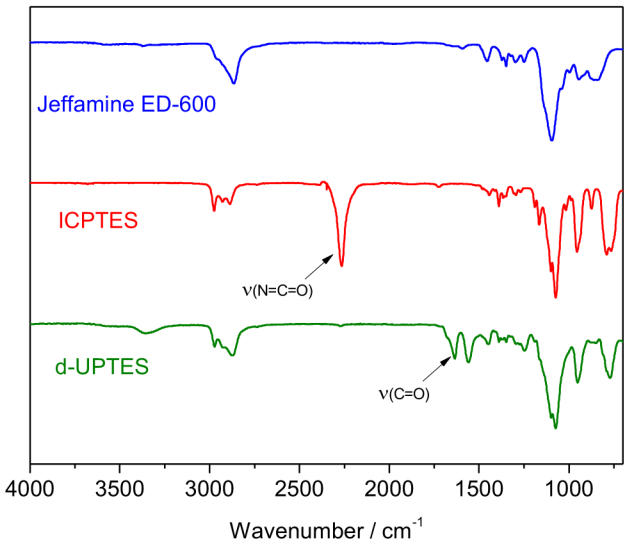

Figure S1. FTIR spectra of Jeffamine ED-600 (blue line), ICPTES (red line) and the d-UPTES intermediate (green line).

2 Synthetic conditions used to prepare ureasil core-shell nanocomposite particles (CSNPs)

Table S1. Composition of undoped CSNP samples prepared using Methods A, B and C.

Method	d-UPTES[a] (µL)	THF (µL)	NH_4OH [b] (mL)	Step 1	Step 2
				TEOS (µL)	**TEOS** (µL)
A	54.8	671.2	3 mL	24 (50%$_{v/v}$ in THF)	-
B	54.8	671.2	3 mL	60 (5%$_{v/v}$ in THF)	60 (5%$_{v/v}$ in THF)
C	54.8	671.2	3 mL	60 (5%$_{v/v}$ in THF)	60 (5%$_{v/v}$ in THF)

[a] Stock solution concentration = 0.56 mol L^{-1} in THF.
[b] Stock solution concentration = 1×10^{-2} mol L^{-1} in water

Table S2. Composition of FITC@CSNP samples and reference samples prepared using the covalent grafting approach.

Sample ID	Step 1	Step 2		
	TEOS[a] (µL)	**TEOS**[a] (µL)	**APTES**[b] (µL)	**FITC-PTES**[c] (µL)
APTES@CSNs-3	60	57	3	-
APTES@CSNs-6	60	54	6	-
APTES@CSNs-15	60	45	15	-
FITC@CSNs-3	60	57	-	3
FITC@CSNs-6	60	54	-	6
FITC@CSNs-15	60	45	-	15

[a] Stock solution concentration = 5% v/v in THF.
[b] Stock solution concentration = 2% v/v in THF.
[c] Stock solution concentration = 22% v/v in THF.

3 Size and stability studies on CSNPs

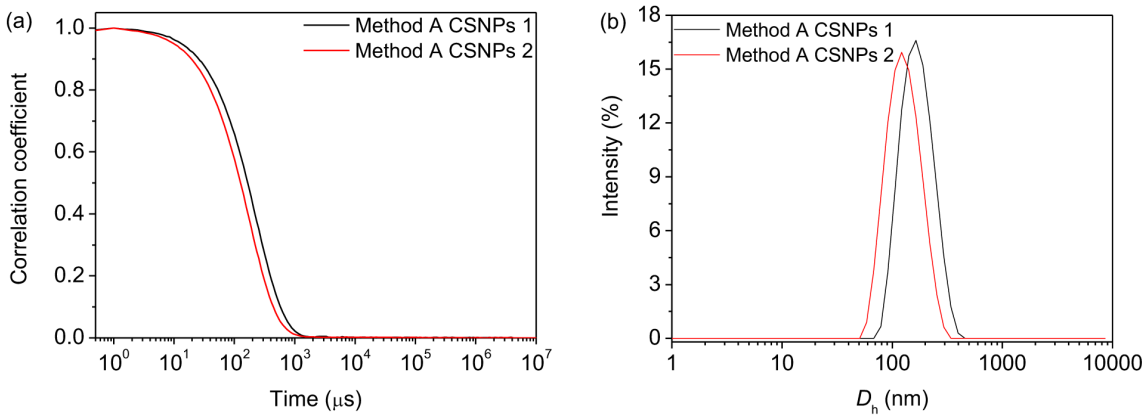

Figure S2. Dynamic light scattering studies on ureasil CSNPs prepared using Method A. (a) Correlation function and (b) size distribution (hydrodynamic diameter, D_h, of two batches of CSNPs prepared on different days using Method A[1].

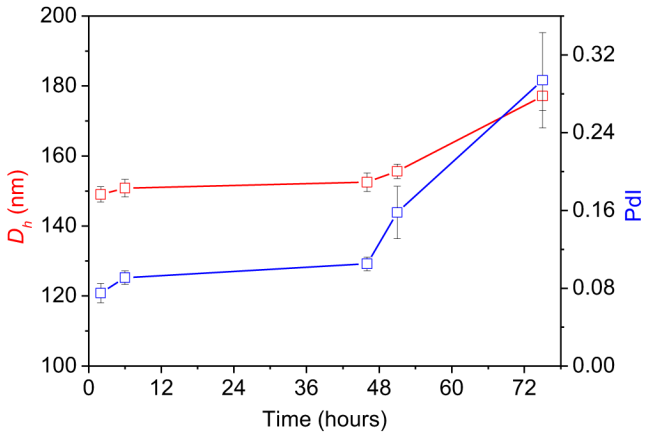

Figure S3. Time-dependent stability of CSNPs synthesized using Method A. The change in the hydrodynamic diameter (D_h, red squares) and the polydispersity index (PdI, blue squares) of 3 different samples as a function of time are shown. The solid lines serve only to guide the eye.

[1] See manuscript for details on Method A.

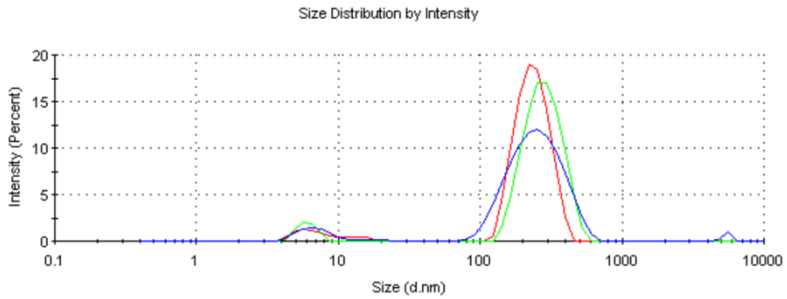

Figure S4. Effect of the tetraethylorthosilicate (TEOS) concentration on the hydrodynamic diameter of CSNPs prepared via Method B[2] using 20% v/v TEOS and after 4 days of ageing. The peaks centred at ~5 nm represent a population of pure TEOS nanoparticles, while those centred at ~200 nm represent the CSNPs. A minor contribution, which is probably due to dust, is also observed at ~6000 nm.

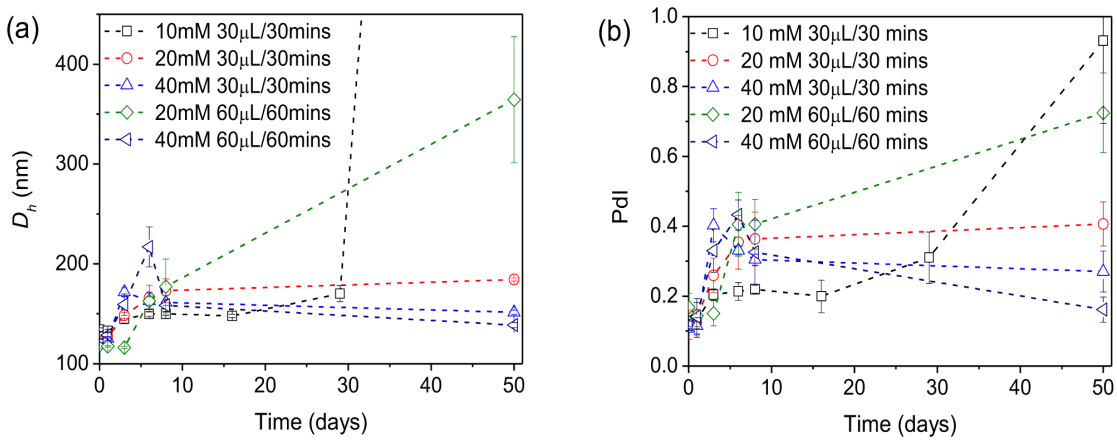

Figure S5. Effect of base concentration (10-40 mM NH_4OH) and TEOS addition rate (μl/min for a total duration of 2 hours) on (a) hydrodynamic diameter and (b) polydispersity of CSNPs prepared using Method C.[3] (

[2] See manuscript for details on Method B.
[3] See manuscript for details on Method C.

4 Emission properties of CSNPs doped or grafted with fluorescent dyes

4.1 Steady-state measurements

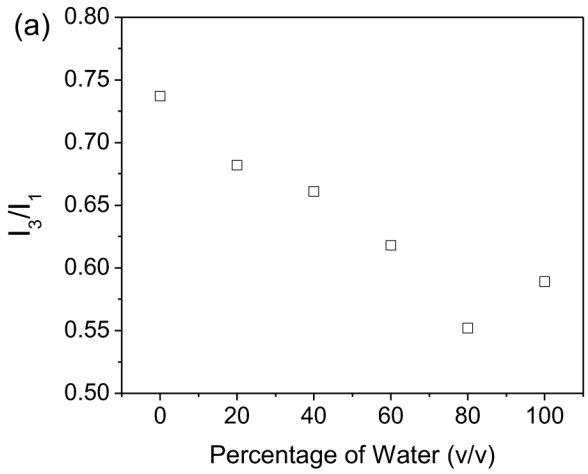

Figure S6. I_3/I_1 fluorescence intensity ratios[4] for pyrene in water/ethanol mixtures at different volume percentage of water (dye conc. = 2.5×10^{-5} mol L^{-1}). λ_{ex} = 335 nm.

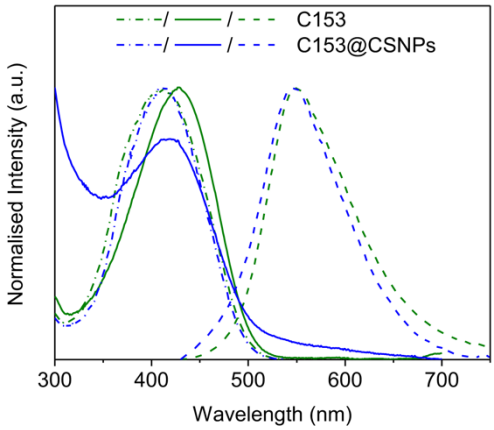

Figure S7. Normalized absorption (solid lines), emission (λ_{ex} = 420 nm, dashed lines) and excitation (λ_{em} = 550 nm, dash-dot lines) spectra of C153 in water (green) and upon incorporation into CSNPs (blue). (dye conc. = 3.6×10^{-5} mol L^{-1}).

[4] See manuscript, Figure 6 for identification of I_1 and I_3 peaks.

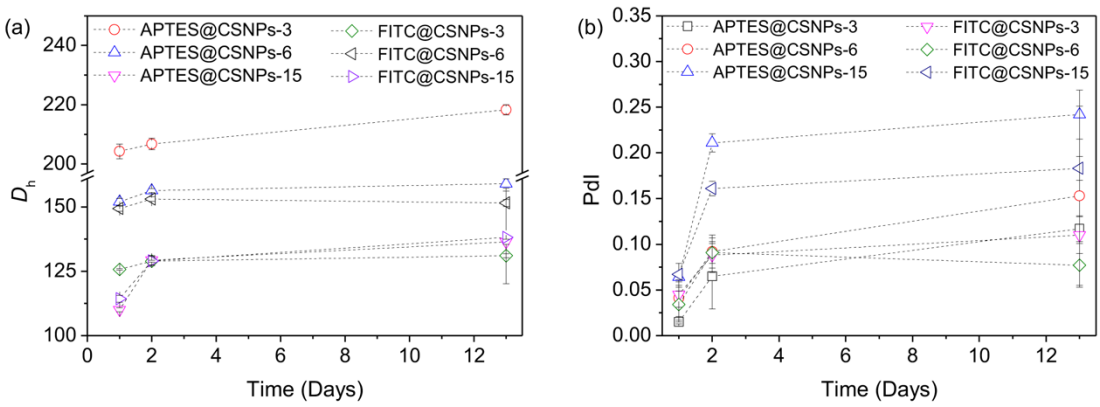

Figure S8. Time-dependent stability of APTES[5]- and FITC[6]-doped CSNPs. (a) Hydrodynamic diameter and (b) polydispersity collected over 13 days for APTES@CSNP and FITC@CSNP sample series.

4.2 Time-resolved measurements

Fluorescence decay curves were modelled using an exponential decay function given by:

$$I(t) = \sum_i \alpha_i \exp(-\frac{t}{\tau_i}) \qquad (1)$$

where I is the fluorescence intensity at time, t, and α_i and τ_i are the pre-exponential factor and characteristic lifetime for the ith component. In this model the intensity is assumed to decay as the sum of individual single exponential decays. When examining a single fluorophore displaying a complex decay it is generally safe to assume that the fluorophore has the same radiative decay rate in each environment. Thus, in this case α_i represents the fraction of the molecules in each environment at t=0.[7]

The fractional contribution f_i of each decay component to the steady-state intensity can be calculated from:

$$f_i = \frac{\alpha_i \tau_i}{\sum \alpha_i \tau_i} \qquad (2)$$

[5] APTES = 3-aminopropyl)triethoxysilane
[6] FITC = fluorescein isothiocyanate
[7] J. R. Lakowicz, in *Principles of Fluorescence Spectroscopy*, Springer, 2006, pp. 142.

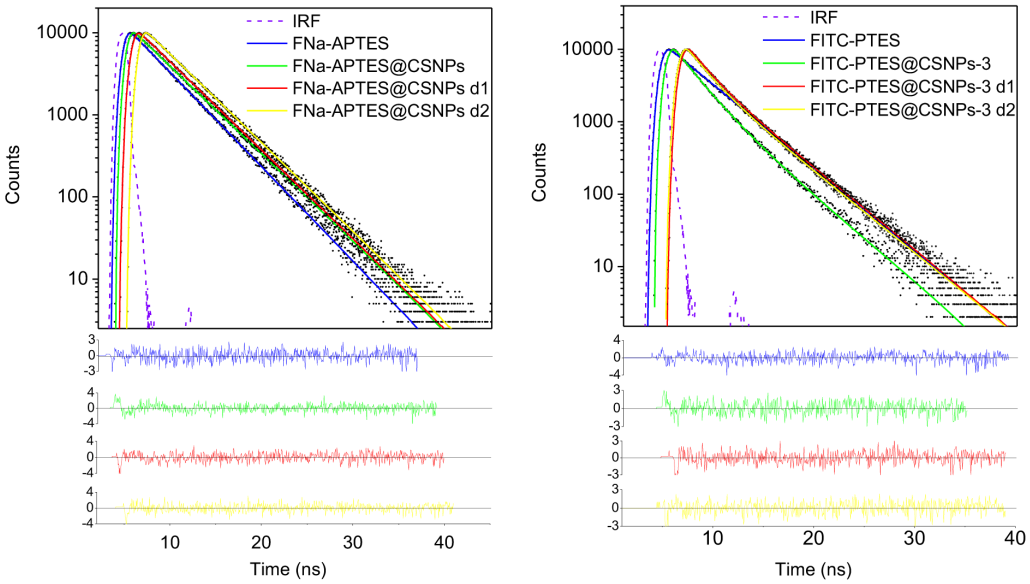

Figure S9. Time-resolved fluorescence investigation of FNa and FITC@CSNPs. Emission decay curves (black dots) and fits (coloured lines) for (a) FNa+APTES and FNa-APTES@CSNPs and (b) FITC-PTES and FITC-PTES@CSNPs before and after dialysis 1 (d1, 24 hours) and dialysis 2 (d2, 48 hours in total) (λ_{ex}= 458 nm and λ_{em}= 515 nm). The weighted residuals for each fit and the instrument response function (IRF, dotted line) are also shown.

Table S3. Time-resolved photoluminescence analyses of FITC-grafted ureasil CSNPs. Decay times (τ_i), fractional contributions (f_i) and chi-squared values (χ^2) resulting from analysis of the decay curves of FNa-APTES, FITC-PTES, FNa-APTES@CSNPs and FITC-PTES@CSNPs, before and after dialysis 1 (d1) and dialysis 2 (d2) (λ_{ex} = 458 nm, λ_{em} = 515 nm).

Sample ID	τ_1 (ns)	f_1	τ_2 (ns)	f_2	χ^2
FNa + APTES	4.06 (±0.01)	1.00 (±0.02)			1.03
FNa-APTES@CSNs	4.08 (±0.01)	1.00 (±0.01)			1.01
FNa-APTES@CSNs-d1	4.03 (±0.01)	1.00 (±0.01)			1.08
FNa-APTES@CSNs-d2	4.02 (±0.01)	1.00 (±0.02)			1.02
FITC-PTES	3.78 (±0.01)	1.00 (±0.04)			1.03
FITC-PTES@CSNs-3	3.78 (±0.02)	0.44 (±0.01)	2.08 (±0.04)	0.56 (±0.01)	1.06
FITC-PTES@CSNs-3-d1	3.86 (±0.01)	0.67 (±0.05)	1.75 (±0.04)	0.33 (±0.03)	1.11
FITC-PTES@CSNs-3-d2	3.85 (±0.01)	0.65 (±0.05)	1.73(±0.02)	0.35 (±0.03)	1.05