Electronic Supplementary Information

Light-responsive aggregation of β-cyclodextrin covered silica nanoparticles

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Synthesis:

The azobenzene linker **(6)** was synthesized according to the literature [1].

Preparation of mono-6-p-toluenesulfonyl-β-cyclodextrin

Mono-tosyl-β-CD was synthesized similar to [2].

β-CD (10 g, 8.8 mmol) and sodium hydroxide (5 g, 125 mmol) were dissolved in 300 mL demineralized water. The solution was cooled down in an ice bath to 0°C. *p*-toluenesulfonic acid (*p*-TosCl) was added in two steps (step 1: 4 g, 21 mmol, step 2: 6 g, 12.4 mmol). After each step, the reaction mixture was stirred for 2 h at -7°C. Afterwards, the mixture was filtered over celite and the filtrate was crystallized over night at 4 °C after adding a 10 % HCl solution. The obtained white product was collected via suction filtration and washed five times with water to remove traces of HCl. Yield: 4.2 g; MS (ESI-MS) = 1311.36 $[M + Na]^+$; FTIR (KBr): ν = 3369, 2928, 2155, 1653, 1599, 1456, 1412, 1365, 1298, 1243, 1177, 1157, 1080, 1029, 946, 837, 814, 757, 706, 668, 607, 579, 553, 530 cm^{-1}; ^{1}H-NMR (600 MHz, DMSO-d_6): δ 7.72 (d, 2H, J = 7.9 Hz), 7.41 (d, 2H, J = 7.8 Hz), 5.61-5.84 (m, 14H), 4.76 - 4.84 (m, 7H), 4.13-4.62 (m, 6H), 3.45-3.72 (m, 28H), 3.16-3.43 (m, overlapping with HDO, 14 H), 2.40 (s, 3H); ^{13}C-NMR (600 MHz, DMSO-d_6): δ 145.2, 133.1, 130.3, 128.0, 102.4, 82.0, 81.2, 73.5, 73.2, 72.9, 72.6, 70.2, 69.4, 60.4, 21.6.

Preparation of mono-6-thio-β-cyclodextrin

Mono-tosyl-β-CD was synthesized similar to [3].

Mono-tosyl- β-CD (7.2 g, 5.6 mmol) was dissolved in DMF and the solution was degassed for 10 min by an argon stream. Potassium thioacetate (2.5 g, 22 mmol) was added to the solution and the reaction was heated to 50 °C over night. Afterwards the solvent was removed under reduced pressure. The residue was dissolved in a small amount of water and a hugh amount of acetone was added. The resulting precipitate was collected by filtration. The white product was then dissolved in aq. NaOH solution (pH = 13) and stirred for 5 h at RT. After that the pH was adjusted to 3 by slowly adding conc HCl to the mixture. Again a large amount of acetone was added and the precipitate was crystallized over night in the fridge. The white precipitate was collected by filtration and washing with acetone. Yield: 4 g; MS (ESI-MS) = 1173.36 $[M + Na]^+$; FTIR (KBr): ν = 3909, 3390, 2928, 2574, 1642, 1415, 1368, 1335, 1301, 1245, 1157, 1079, 1029, 946, 840, 756, 707, 650, 579, 531 cm^{-1}; ^{1}H-NMR (600 MHz, DMSO-d_6) = 5.61-5.80 (m, 14H), 4.79-4.88 (m, 7H), 4.47-4.52 (m, 6H), 3.27-3.75 (m, 38H), 2.71-2.97 (m, 2H),

2.1 (t, 1H, J = 7,6 Hz); ^{13}C-NMR (600 MHz, DMSO-d_6): δ 102.35, 84.55, 81.93, 73.48, 72.86, 72.42, 60.25, 26.07.

Preparation of "bare" silica nanoparticles

The bare silica nanoparticles were synthesized following a literature procedure [4, 5].

Bare silica nanoparticles **(1)** were synthesized using the classical *stoeber* method [3]. Therefore 3.8 mL tetraethylorthosilicate were added quickly to a solution of 5.7 mL ammonium hydroxide (28%) in 114 mL absolute ethanol and stirred over night at RT. Afterwards the particles were purified by three centrifugation and redispersion steps in absolute ethanol. The particles were stored at 4 °C before use. This synthesis should lead to silica nanoparticles with an average size of 50 nm.

Preparation of amino-functionalized silica nanoparticles

The amino covered nanoparticles were synthesized following a literature procedure [5].

The before synthesized bare silica nanoparticles were functionalized with 3-Aminopropyltriethoxysilane (APTES) by adding 3 mL of APTES under vigorous stirring to a bare silica nanoparticle solution in absolute ethanol at RT. The resulting particles were purified by three centrifugation and redispersion steps in absolute ethanol and were stored at 4 °C before use.

Preparation of allyl-functionalized silica nanoparticles

3 mL of Octenyltrichlorosilane was added quickly to a silica nanoparticle solution in toluene under argon atmosphere. The mixture was stirred over night at RT. Unreacted octenyltrichlorosilane was removed by three centrifugation and redispersion steps in DMSO (3 times) and toluene (3 times). The particles were stored at 4 °C before use.

Preparation of CD-NH-NP

The procedure was carried out similar to [6]. Therefore the APTES functionalized particles were redispersed in an aqueous KOH solution (pH = 12) and freshly prepared mono-tosyl-β-CD (0.3 g, 0.23 mmol) was added to the mixture under vigorous stirring. The solution was stirred over night at 80 °C. The resulting CD covered particles were purified first by two times centrifugation and redisperison in DMSO to remove the excess of mono-tosyl- β-CD and second by two times centrifugation and redispersion in DMSO to remove traces of

unreacted mono-tosyl- β-CD and three times in water. The cleaned particles were stored at 4 °C before use.

Preparation of CD-SH-NP

Allyl-functionalized particles were redispersed in dry acetonitrile and added to a Schlenck flask. β-mono-SH-CD (0.3 g, 0.26 mmol) and AIBN (0.2 g, 1.2 mmol) were added under argon atmosphere and the solution was degassed with argon for 10 min. Afterwards the mixture was stirred for 48 h at 80 °C. The resulting β-CD covered particles were purified by two times centrifugation and redispersion in DMSO to remove unreacted β-CD and three times in water. The product was stored at 4 °C before use.

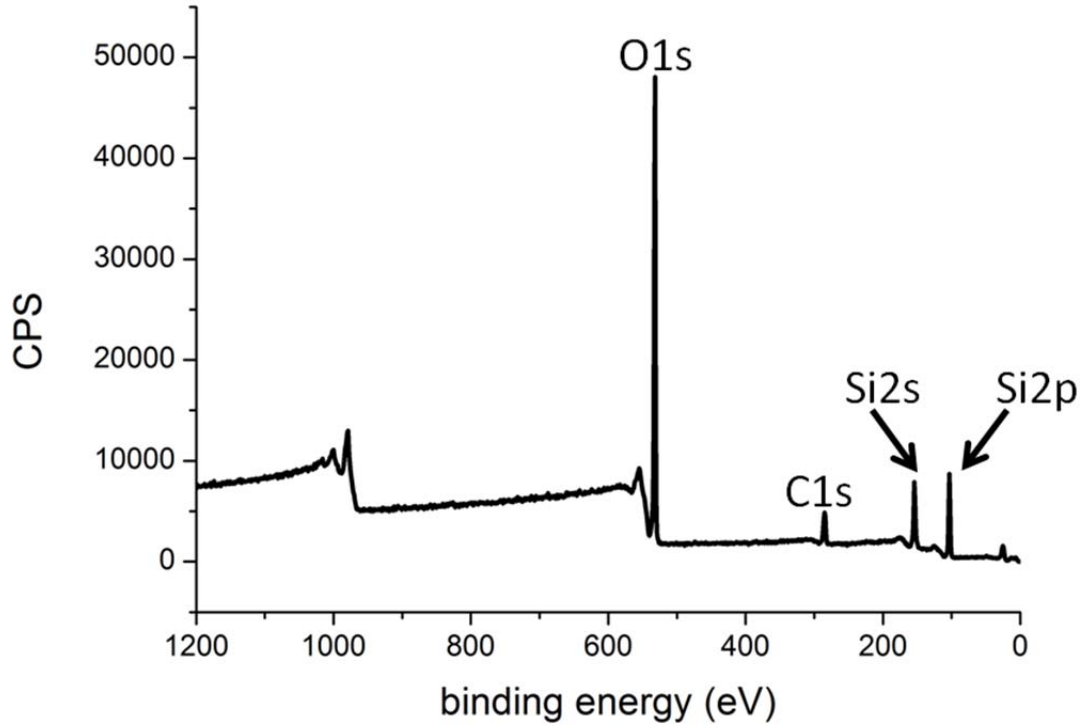

Figure S1: XPS survey spectrum of the bare silica nanoparticles **(1)**.

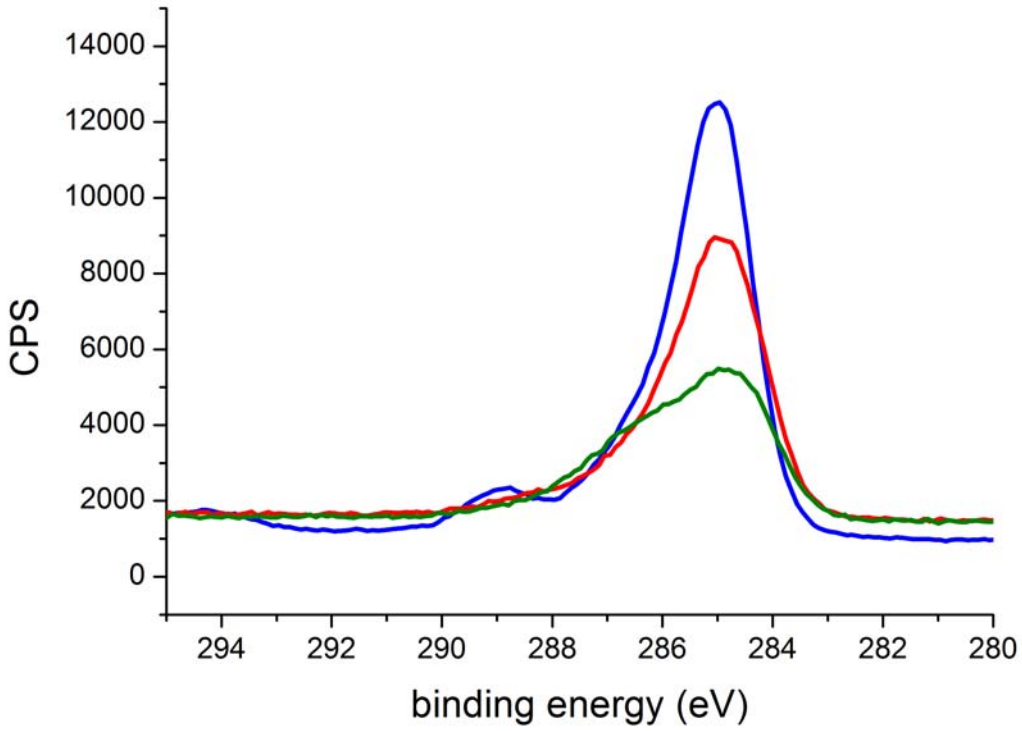

Figure 2: XPS narrow scan spectrum of the C1s signal of the bare particles (**(1)**, green), the APTES particles (**(2)**, red curve) and the CD covered particles (**(4)**, blue curve).

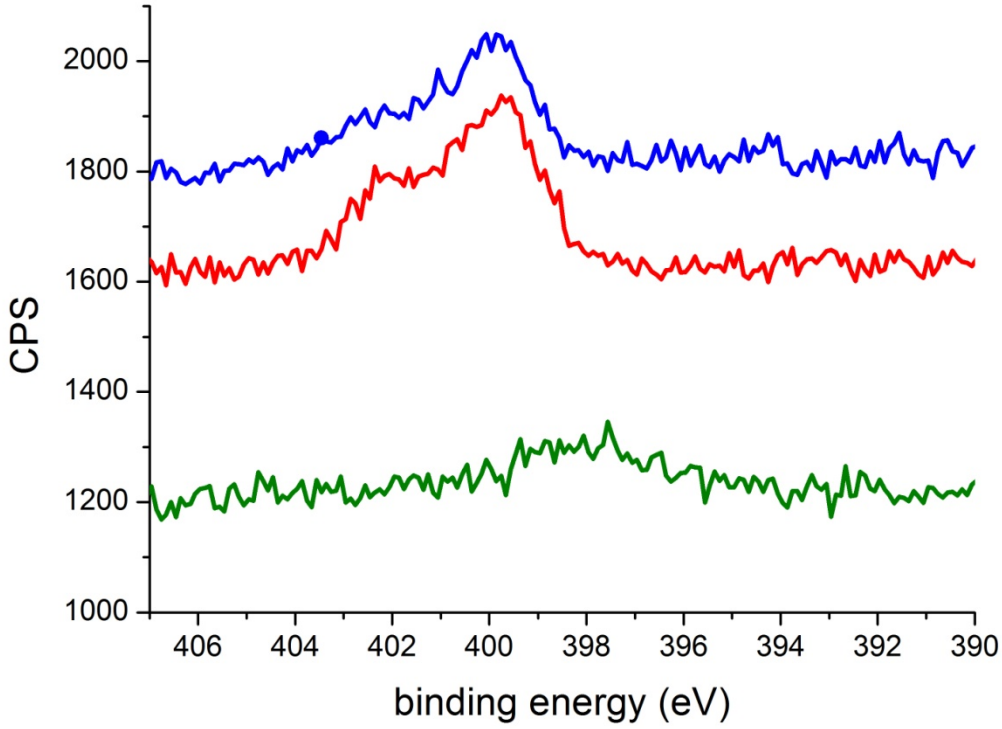

Figure 3: XPS narrow scan spectrum of the N1s signal of the bare particles (**(1),** green), the APTES particles (**(2)**, red curve) and the CD covered particles ((**4)**, blue curve).

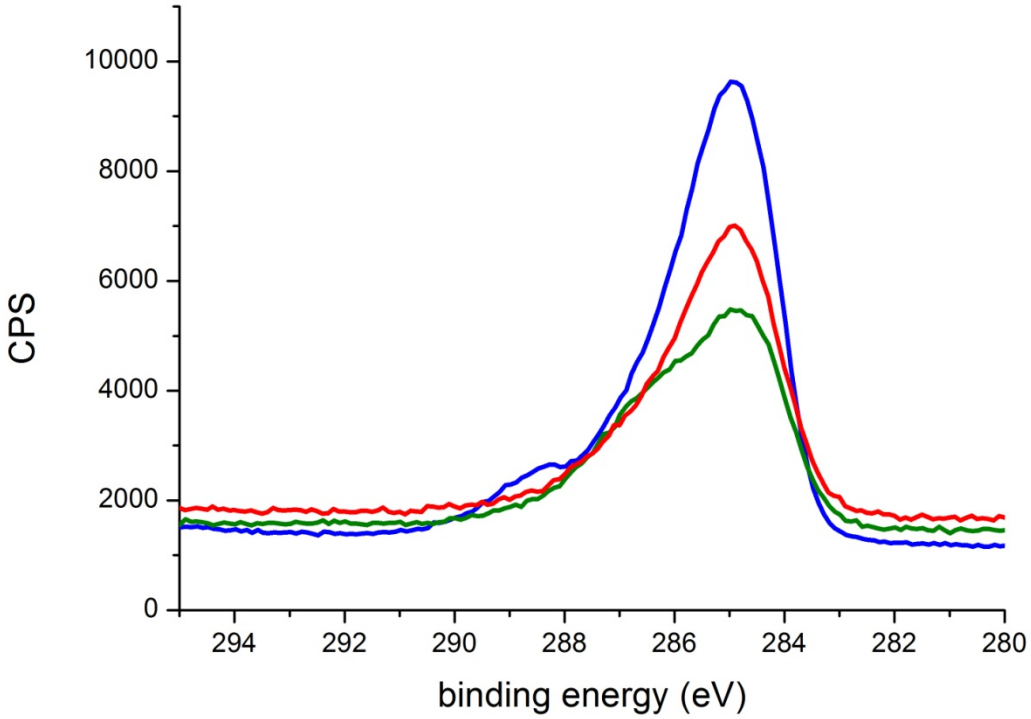

Figure 4: XPS narrow scan spectrum of the C1s signal of the bare particles (**(1)**, green), the allyl particles (**(3)**, red curve) and the CD covered particles (**(5)**, blue curve).

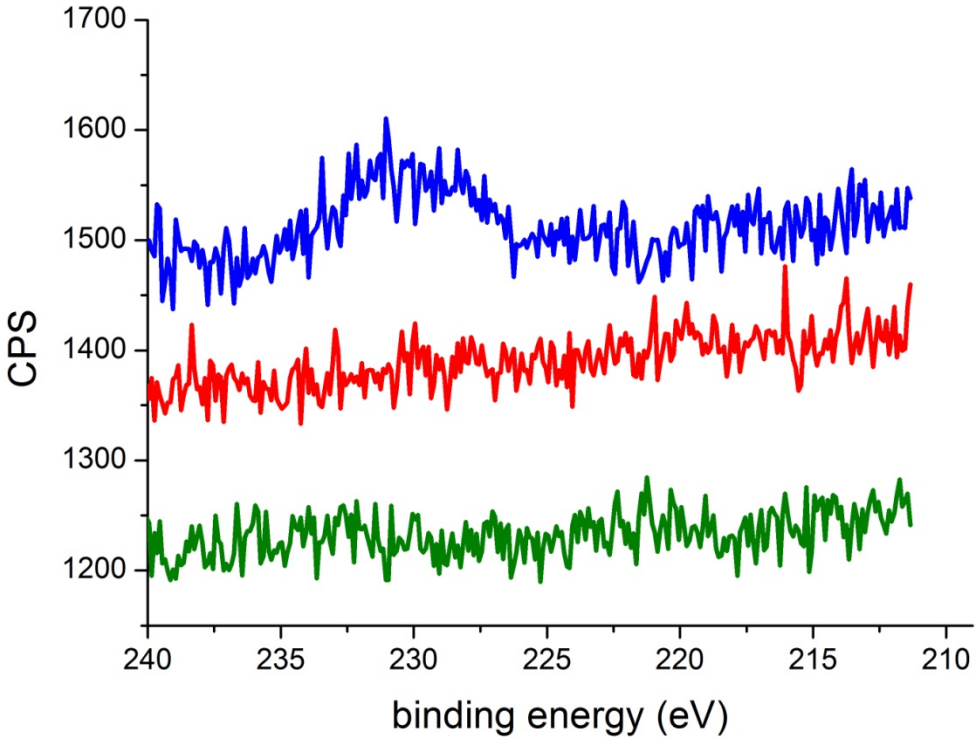

Figure 5: XPS narrow scan spectrum of the S1s signal of the bare particles (**(1)**, green), the allyl particles (**(3)**, red curve) and the CD covered particles (**(5)**, blue curve).

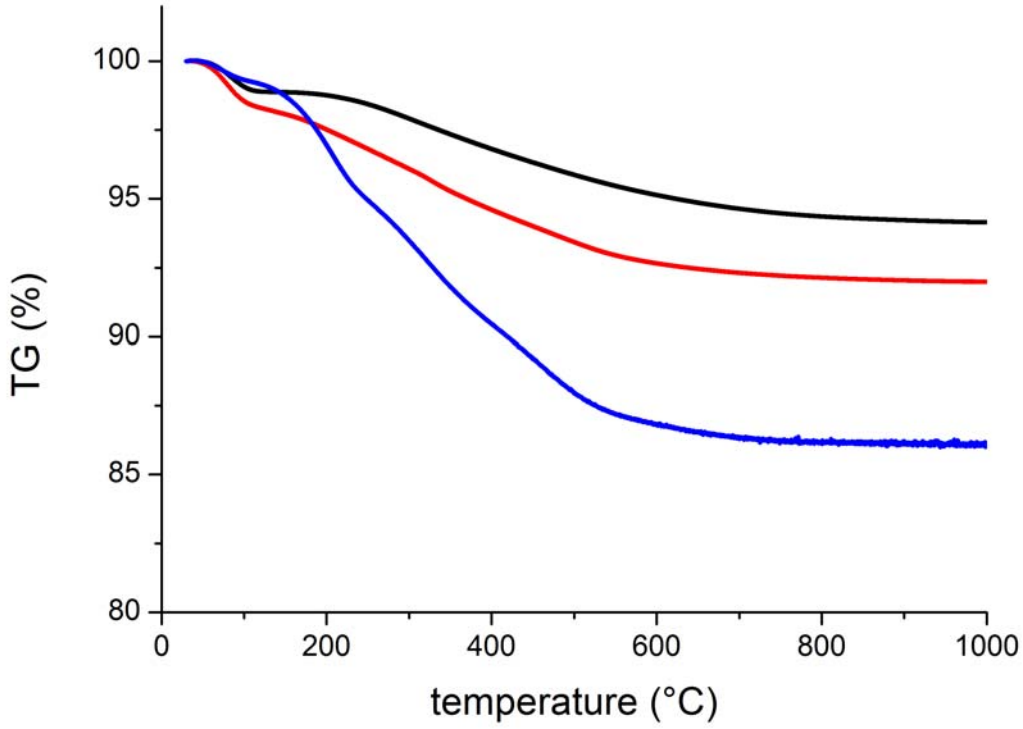

Figure S6: TGA curves of the bare particles (**(1)**, black curve), the APTES covered particles (**(2)**, red curve) and the CD covered particles (**(4)**, blue curve).

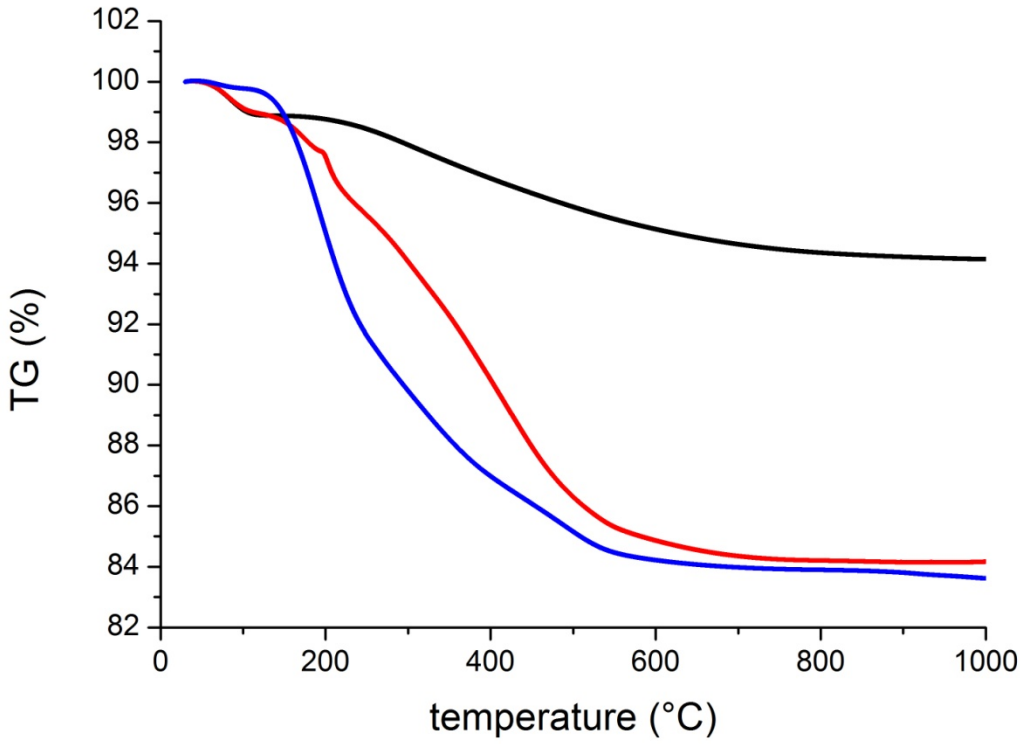

Figure S7: TGA curves of the bare particles (**(1)**, black curve), the allyl covered particles (**(3)**, red curve) and the CD covered particles (**(5)**, blue curve).

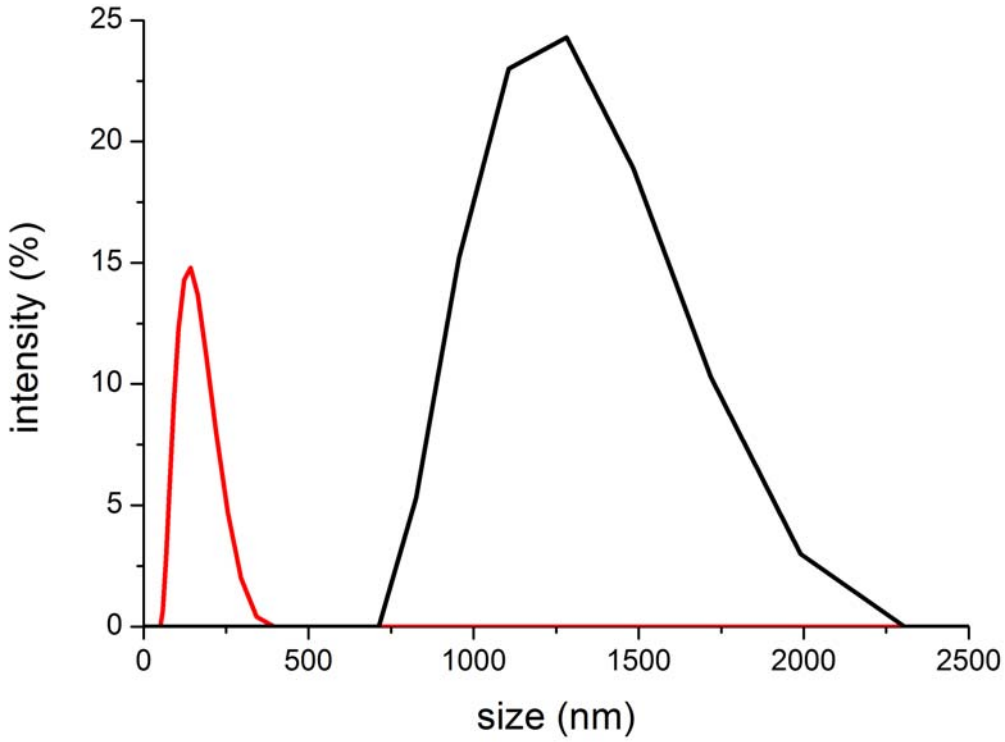

Figure S8: Size distribution according to DLS measurements of β-CD-NH-NP **(4)** with c = 0.085 mg/mL before (red curve) and after addition of the azobenzene linker **(6)** and 20 min visible light irradiation (black curve).

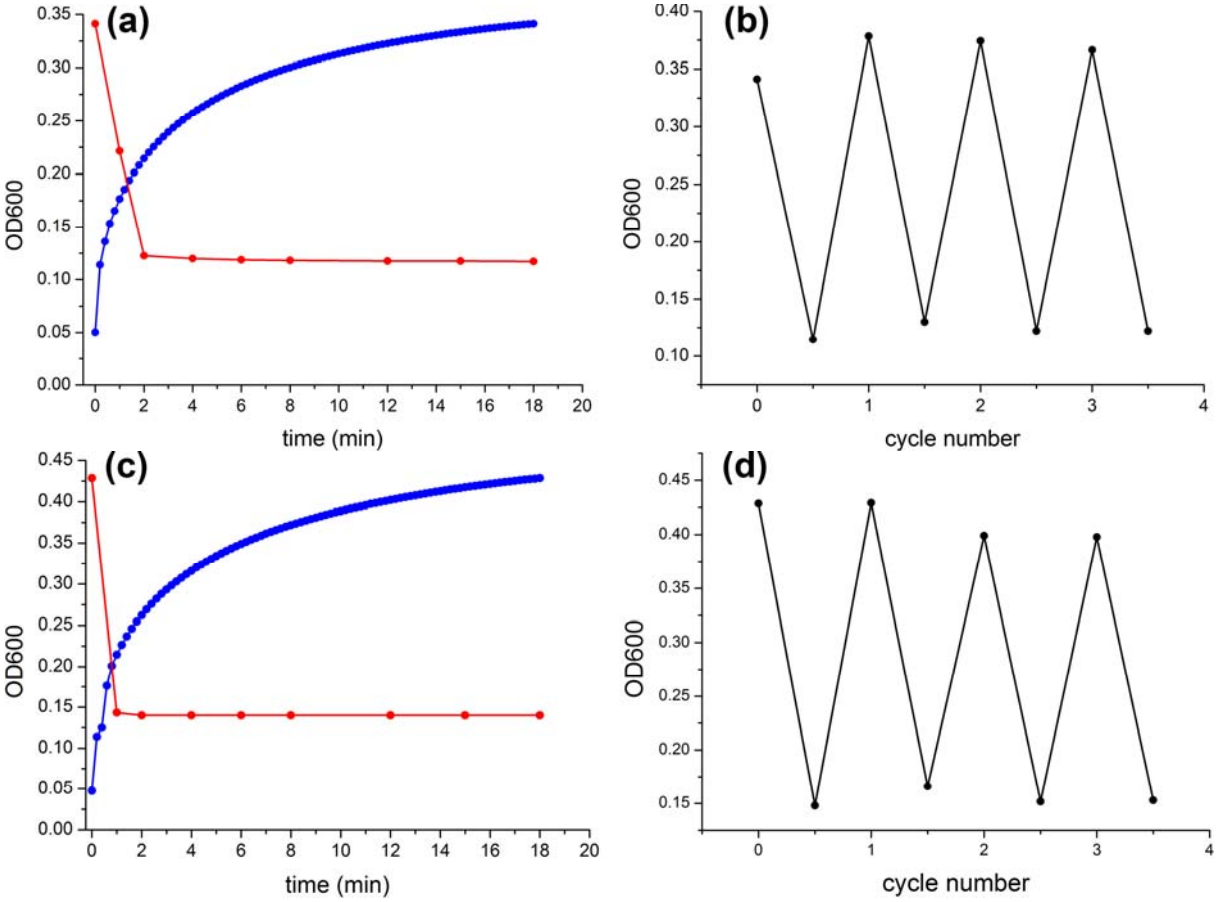

Figure S9: Light-responsive aggregation and dispersion of CD covered silica nanoparticles **(4)** and **(5)** (c = 0.085 mg/mL) in presence of the bifunctional azobenzene linker **(6)** (40 µM) in phosphate buffer (pH = 7.2). (a)Time dependent increase and decrease of OD600 by irradiation with visible light (λ = 450 nm) and UV light (λ = 365 nm) of CD particles **(4)**. (b) Reversible light-responsive aggregation and dispersion of CD particles **(4)**. (c)Time dependent increase and decrease of OD600 by irradiation with visible light (λ = 450 nm) and UV light (λ = 365 nm) of CD particles **(5)**. (d) Reversible light-responsive aggregation and dispersion of CD particles **(5)**.

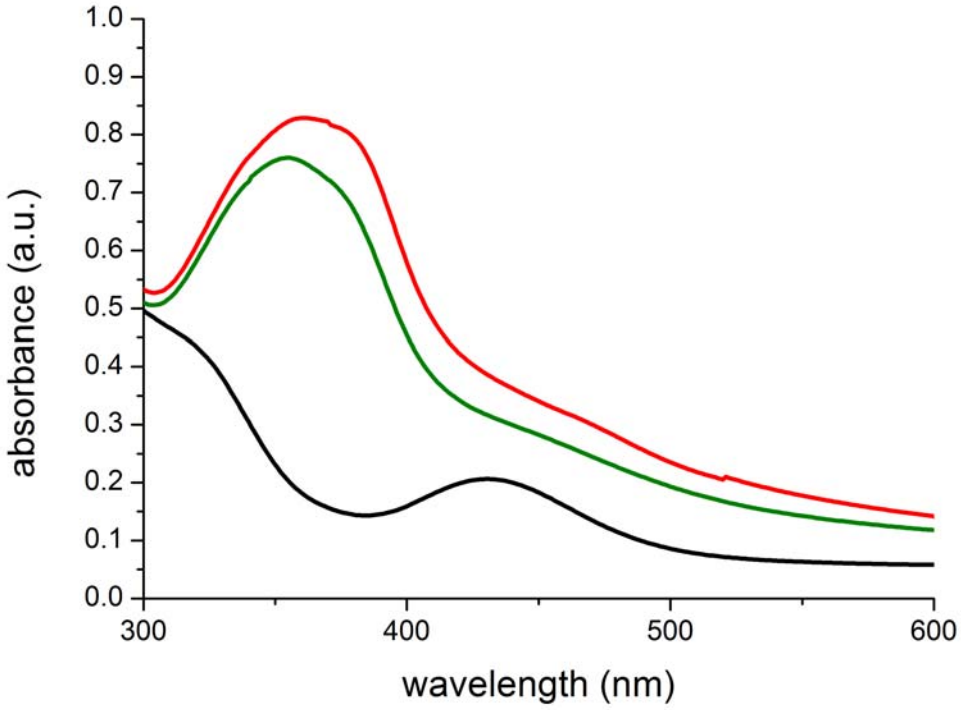

Figure S10: UV-vis spectra of β-CD-SH-NP **(5)** (c = 0.085 mg/mL) in phosphate buffer after addition of the azobenzene linker **(6)** (c = 20μM): Before (*trans*, red curve), after UV light irradiation (λ = 365 nm) for 20 min (*cis*, black curve) and after visible light irradiation (λ = 455 nm) for 20 min (re*trans*, green curve).

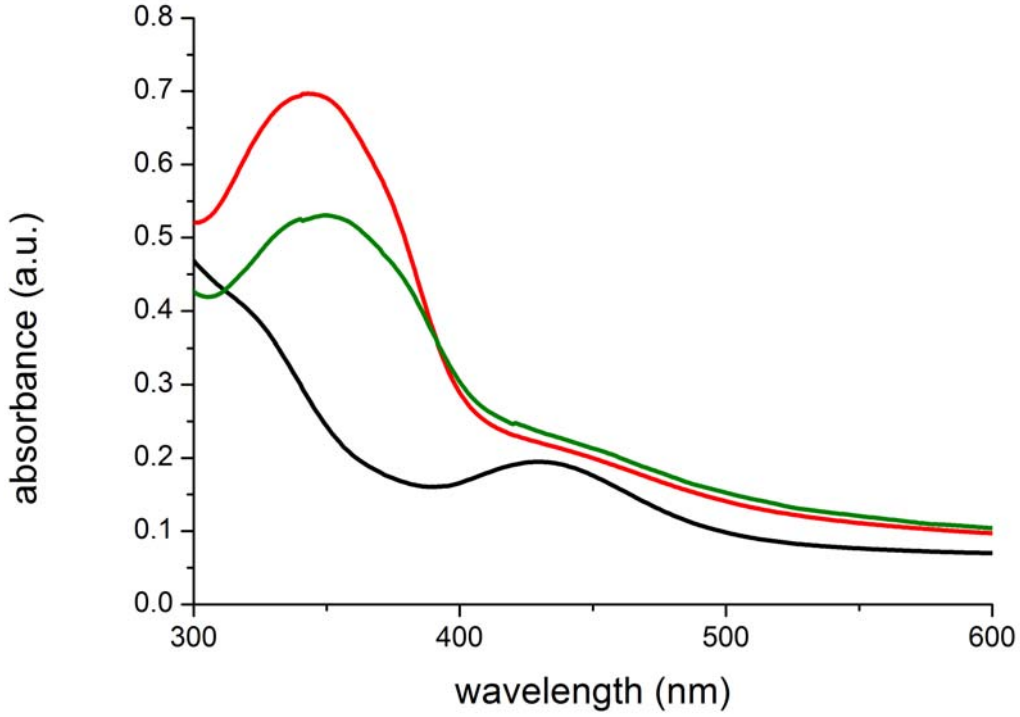

Figure S11: UV-vis spectra of β-CD-NH-NP **(4)** (c = 0.085 mg/mL) in phosphate buffer after addition of the azobenzene linker **(6)** (c = 20μM): Before (*trans*, red curve), after UV light irradiation (λ = 365 nm) for 20 min (*cis*, black curve) and after visible light irradiation (λ = 455 nm) for 20 min (re*trans*, green curve).

References

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