

Support information

Selectively grafting polymer from the interior or/and exterior surfaces of bio-reducible and temperature-responsive nanocapsules

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Experimental Section

1. Materials

Potassium persulfate (KPS) was recrystallized twice from water. Acryloyl chloride was freshly distilled before use. N-Isopropylacrylamide (NIPAM, 98%, TCI), poly(ethylene glycol) methacrylate (PEGMA, average $M_n \sim 360$, Aldrich), and 2-(dimethylamino)ethyl acrylate (DMAEA, Alfa, 99%) were purified by passing through a column filled with basic alumina to remove the inhibitors. Ceric ammonium

nitrate (CAN), 3-(trimethoxysilyl)propyl methacrylate (MPS, TCI, 98%), Tetraethoxysilane (TEOS), Ammonia (28% in water), absolute ethanol, dichloromethane, Cystamine dihydrochloride, hydrofluoric acid (40 wt %), and nitric acid were purchased from Sinopharm Chemical Reagent Co. Ltd. (SCRC, China) and used as received. N,N'-cystaminebisacrylamide (CBA) was synthesized according to Paolo's method.¹ ¹H NMR (300 MHz, d₆-DMSO): δ 8.31 (1H), δ 6.22 (dd, J = 17.1, 9.9 Hz, 1H), δ 6.09 (dd, J = 17.1, 2.4 Hz, 1H), δ 5.60 (dd, J = 9.9, 2.4 Hz, 1H), δ 3.42 (dd, J = 12.7, 6.3 Hz, 2H), δ 2.82 (t, J = 6.8 Hz, 2H).

2. Synthesis and modification of silica nanoparticles

MPS functionalized silica nanoparticles with diameters of about 100 nm were prepared according to modified stöber's method.² The preparation procedure is as follows: Absolute ethanol (100.0 mL) and ammonia (6.5 mL) were introduced in a 250-mL Erlenmeyer flask equipped with a magnetic stirrer. After equilibration, TEOS (7.0 mL) was added slowly and the reaction was allowed to last for 24 h under permanent stirring at 30 °C. To graft double bonds onto the silica surface, MPS (2 ml) was added directly into the particle suspension. The reaction was allowed to proceed for another 24 h. After that, several cycles of centrifugation and redispersion in ethanol were performed to remove the remaining reactant. Finally the MPS modified silica nanoparticles (SiO₂-MPS) were dispersed in water (30.0 mg/ml).

Study of controlled release behaviors

Disulfide linkages in the wall of the nanocapsules provide the nanocapsules with redox-sensitive and biodegradable properties. To demonstrate that dithiothreitol (DTT)

triggers degradation, DTT (10.0 mg) was introduced into the nanocapsule suspension (2.0 mL) at room temperature and the milky suspension became transparent within 20 min. The hydrodynamic diameter of the nanocapsules before and after DTT degradation was measured by dynamic light scattering (DLS).

Herein, FITC was used as a model molecule to investigate the controlled release behavior of the nanocapsules. FITC-trapped silica nanoparticles (FITC@SiO₂-MPS) were prepared according to the method of Gao et al.³ A typical synthesis procedure was depicted as follows: FITC (10.6 mg) reacted with organosilicon coupling agent APS (11.5mg) in 5.0mL anhydrous ethanol for at least 12 h at room temperature. Then this solution together with TEOS (3.5 mL) was added into a homogeneous mixture of ethanol (45.0 mL) and ammonia (3.4 mL). After stirring for 24 h, MPS (0.70 mL) was added slowly to modify the surface of the FITC trapped silica particles. After 24 h, the obtained FITC trapped, MPS-modified silica particles were washed repeatedly with ethanol and dispersed in deionized water (30.0 mg mL⁻¹). After seeded precipitation polymerization using FITC@SiO₂-MPS as seed, surface graft polymerization were carried out. Then FITC@P(NIPAM-*co*-PEGMA)@PDMAEA nanocapsules were obtained by HF etching, and washed by deionized water repeatedly, the FITC-trapped polymeric nanocapsules (45.0 mg) were dispersed in deionized water (10 mL). The suspension of 5 mL was dialyzed against deionized water at 20 °C, 5 mL of the suspension was dialyzed against deionized water at 20 °C in the presence of DTT. Fluorescence measurements were performed to record the release kinetics of FITC.

Characterizations

^1H NMR spectra of hairy nanocapsules and CBA were performed on a Bruker AC 400 MHz NMR spectrometer using D_2O and $\text{d}_6\text{-DMSO}$ as solvent. FT-IR was performed on an EQUIVOX55 (Bruker) FT-IR spectrophotometer. The dried samples were mixed with KBr to form pellets. X-ray photoelectron spectroscopy (XPS) measurements were carried out on a Thermo-VG Scientific Escalab 250 X-ray photoelectron spectrometer equipped with a monochromatized Al K Alpha X-ray source. High resolution TEM (HRTEM) images were obtained using a JEM-2010 transmission electron microscopy operating at 200 KV. SEM images were obtained using a SIRION200 scanning electron microscopy. Dynapro-MS800 instrument, equipped with an 830 nm wavelength laser, was used to determine the hydrodynamic radius (R_h) and polydispersities of the nanocapsules. The samples were filtered through a 0.45 μm filter and allowed to equilibrate at each temperature for 10 min before measurement. Three separate size measurements were performed for each data point. Fluorescence emission spectra were obtained using an RF-5301PC (SHIMADZU) spectrofluorimeter.

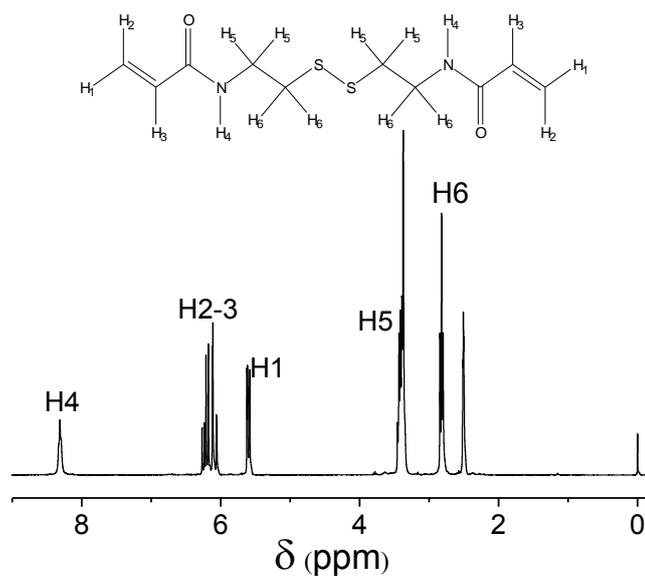


Figure S1 ¹H NMR spectrum of CBA run in d₆-DMSO.

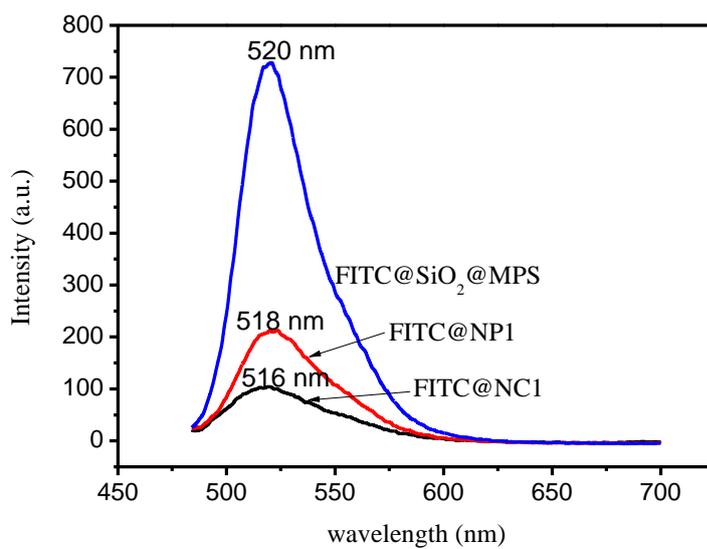


Figure S2 The fluorescence spectra FITC@SiO₂@MPS nanoparticles, FITC@SiO₂-P(NIPAM-*co*-PEGMA)@PDMAEA nanoparticles and FITC@P(NIPAM-*co*-PEGMA)@PDMAEA nanocapsules.

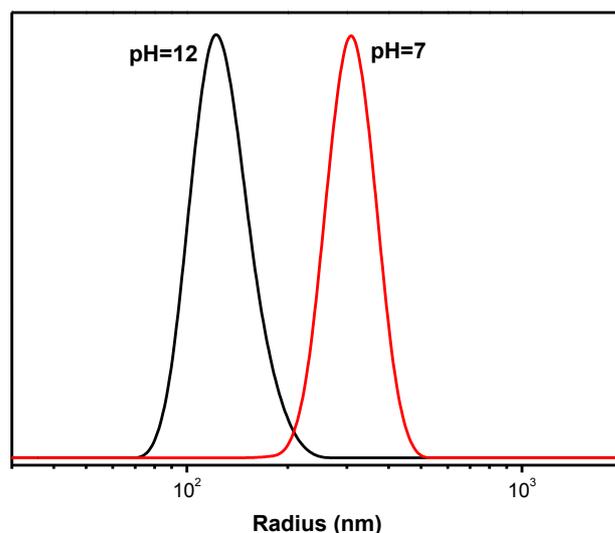


Figure S3 Hydrodynamic Radius of air@P(NIPAM-*co*-PEGMA)@PDMAEA at pH=7 and 12 in water.

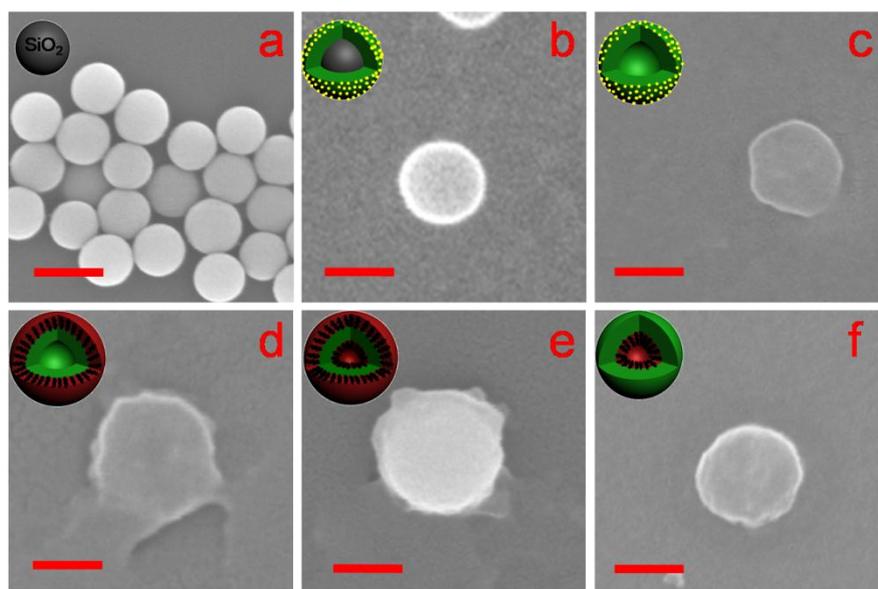


Figure S4 SEM images of (a) SiO₂@MPS, (b) SiO₂@P(NIPAM-*co*-PEGMA) nanoparticles, (c) P(NIPAM-*co*-PEGMA) nanocapsules, (d) air@P(NIPAM-*co*-PEGMA)@PDMAEA, (e) PDMAEA@P(NIPAM-*co*-PEGMA)@PDMAEA, (f) PDMAEA@P(NIPAM-*co*-PEGMA). The scale bar is 100 nm.

Reference

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- (3) Gao, H. F.; Yang, W. L.; Min, K.; Zha, L. S.; Wang, C. C.; Fu, S. K. *Polymer* **2005**, *46*, 1087.