Journal of Macromolecular Science, Part A
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713597274

Crosslinked Polymeric Nanocapsules Via Surface-initiated Atom Transfer Radical Polymerization from SiO_2 Nano-templates

Pengcheng Du[a]; Peng Liu[a]
[a] Institute of Polymer Science and Engineering, College of Chemistry and Chemical Engineering, Lanzhou University, Lanzhou, People's Republic of China

Online publication date: 21 September 2010

To cite this Article Du, Pengcheng and Liu, Peng(2010) 'Crosslinked Polymeric Nanocapsules Via Surface-initiated Atom Transfer Radical Polymerization from SiO_2 Nano-templates', Journal of Macromolecular Science, Part A, 47: 11, 1080 — 1083
To link to this Article: DOI: 10.1080/10601325.2010.511519
URL: http://dx.doi.org/10.1080/10601325.2010.511519

Journal of Macromolecular Science, Part A: Pure and Applied Chemistry (2010) **47**, 1080–1083

ISSN: 1060-1325 print / 1520-5738 online
DOI: 10.1080/10601325.2010.511519

Taylor & Francis
Taylor & Francis Group

Crosslinked Polymeric Nanocapsules Via Surface-initiated Atom Transfer Radical Polymerization from SiO_2 Nano-templates

PENGCHENG DU and PENG LIU*

Institute of Polymer Science and Engineering, College of Chemistry and Chemical Engineering, Lanzhou University, Lanzhou, People's Republic of China

Received April 2010, Accepted May 2010

The aim of the present work was to develop the crosslinked polymeric nanocapsules for drug delivery from the SiO_2 nano-templates via surface-initiated atom transfer radical polymerization (SI-ATRP) technique. The crosslinked polymeric nanocapsules were fabricated via the SI-ATRP of 2-hydroxyethyl acrylate (HEA) from initiator modified silica nano-templates. After the hydroxyl side-groups of the polymer grafted silica nanoparticles (SN@PHEA) were crosslinked with hexamethylene diisocyanate (HDI), the silica templates encapsulated in the crosslinked polymer shells were removed by being etched with HF to produce the crosslinked polymeric nanocapsules. The diameter of the polymeric nanocapsules is in the range of 20–40 nm, characterized by transmission electron microscopy (TEM).

Keywords: Nanocapsules, drug delivery, templates, surface-initiated, atom transfer radical polymerization

1 Introduction

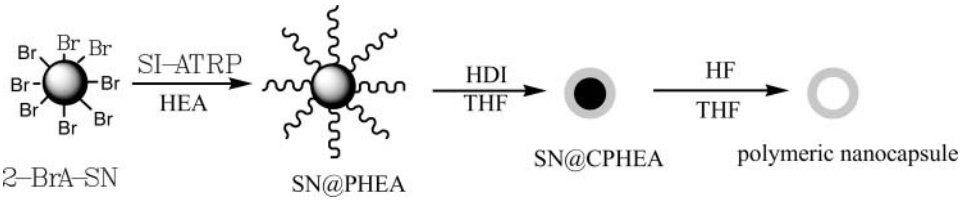
The polymeric nano-/microcapsules, especially the nanometer-sized ones, have attracted intense research interest in recent years due to their unique properties, and their broad potential applications in many field (1,2), such as drug delivery or controlled release systems (3,4), gene delivery (5), protective shells for cells and enzymes (6), catalyst (7), sensor (8), nano-reactor (9), etc.

In order to meet the growing need for encapsulation materials, several strategies have been developed for the fabrication of the polymeric nano-/microcapsules (10), such as emulsion polymerization and interfacial polymerization techniques (11,12), micellization of block copolymers (13,14), the template methods via layer-by-layer self-assembly technique (15) and surface polymerization technique (16), and so on. In some cases of polyelectrolyte multilayer micrometer-sized spheres have been prepared by the step-wise assembling of sodium polystyrene sulfonate (PSS) and polyallylamine hydrochloride (PAH) based on the monodisperse weakly crosslinked melamine formaldehyde (MF) colloidal particles, after the MF cores were decomposed in aqueous media at pH values below 1.6, 2 μm polyelectrolyte microcapsules was obtained (17).

In addition to these different approaches for making hollow polymeric spheres, a variety of novel techniques have evolved for producing polymeric hollow spheres or hollow latex particles. The surface-initiated controlled/"living" radical polymerization was used to design the well-defined shell structure and control the shell thicknesses of the polymeric nanocapsules (18–20). Walt et al. fabricated about 3 μm hollow microsphere by coating silica microsphere templates with poly(benzyl methacrylate) (PBzMA) using surface-initiated ATRP of benzyl methacrylate on silica nanoparticles and the removal of the silica templates by hydrofluoric acid (HF) treatment (21).

However, most of these hollow spheres are above 200 nm in size, the large size microcapsules are usually not effective for biomedical applications since cell uptake is limited. To overcome this drawback, polymeric nanocapsules were prepared: Diameter of 100 nm vesicles was prepared by polymerizing the spontaneous vesicles anionic maleic surfmer (HEC12-Na) and cationic monomer (MAETAC)[22]. About 50 nm polystyrene nanocapsules were prepared by grafting PS-*b*-PMMA block copolymer from the silica templates via SI-ATRP, and then etching the template with the HF after crosslinking the PS intermediate layer obtained by ultraviolet irradiation (1)

*Address correspondence to: Peng Liu, Institute of Polymer Science and Engineering, College of Chemistry and Chemical Engineering, Lanzhou University, Lanzhou 730000, People's Republic of China. Tel: +86-0931-8912516; Fax: +86-0931-8912582; E-mail: pliu@lzu.edu.cn



Sch. 1. Schematic illustration of the process the preparation of crosslinked poly(2-hydroxyethyl acrylate) (PHEA) nanocapsules.

In the present work, we describe a process for making 20–40 nm crosslinked PHEA nanocapsules by using surface-initaited living radical polymerization. The hydroxyl side-groups of the polymer grafted silica nanoparticles (SN@PHEA) were crosslinked with hexamethylene diisocyanate (HDI). Then the silica templates encapsulated in the crosslinked polymer shells were removed by being etched with HF to produce the crosslinked nanometer-size polymeric nanocapsules (Sch. 1).

2 Experimental

2.1 Materials and Reagents

Nano-SiO_2particles with particle size of 10 nm used was MN1P obtained from Zhoushan Mingri Nano-materials Co. Ltd., Zhejiang, China. It was dried in vacuum at 110°C for 48 h before use.

3-Aminopropyltriethoxysilane (APTES) was purchased from Gaizhou Chemical Industrial Co. Ltd., Liaoning, China. 2-Bromopropiomyl bromide was used as received from Aldrich Chemical Co. 2-Hydroxyethyl acrylate was used as analytical reagent grade from aladdin. Cu(I)Br was purchased from Tianjin Chemical Co., Tianjin, China. 2, 2'-Bipyridine (bpy) (A.R., 97.0%) provided by Tianjin Chemical Co., China was recrystallized twice from acetone. Hexamethylene diisocyanate (HDI) were obtained from Aldrich and used as received. Toluene, tetrahydrofuran (THF), dimethylformamide (DMF), methanol, hydrofluoric acid and other solvents used were all of analytical reagent grade from Tianjin Chemical Co., China, and were used without further purification. Distilled water was used throughout.

2.2 Preparation of Crosslinked Polymeric Nanocapsules

2.2.1. *Preparation of the Initiator Modified Silica Nanoparticles*

The Bromine initiator immobilized on the surface of nano-SiO_2particles (SN) were prepared by the method reported previously (23): after 2.0 g AP@SN was dispersed into 50 ml anhydrous THF containing 4 ml TEA under electromagnetic stirring in an ice bathing. A solution of 2-bromopropiomyl bromide (2 mL) and anhydrous THF (10 mL) was slowly added to the dispersion with stirring for 24 h at the room temperature. Then the BrA-SN was centrifuged and washed with THF and ethanol thoroughly, then dried in vacuum for the subsequent polymerization.

2.2.2. *Preparation of SN@PHEA by ATRP*

In a typical ATRP of HEA from the surface of SiO_2nanoparticles (BrA-SN), the living radical polymerization was performed by the followed procedure: BrA-SN 0.5 g was dispersed in methanol, then HEA 150 mmol (15.7 mL), 215 mg (1.5 mmol) of CuBr, and 470 mg (3 mmol) of bpy were added into a three-neck flask. The reaction was performed for 24 h at 70°C in an atmosphere of nitrogen and was terminated by opening the system to air. The as-prepared hybrids were purified by centrifugation and washed by repeating the cycles of centrifugation in methanol and water, then dried in vacuum at room temperature.

2.2.3. *Crosslinking of the SN@PHEA Composite Particle*

Poly (2-hydroxyethyl acrylate) grafted nano-SiO_2particles (SN@PHEA) 0.20 g was dispersed in anhydrous THF (100 mL) with stirring and ultrasonic vibrations. 0.024 mL HDI was added into the mixture at room temperature under electromagnetic stirring for 12 h. After crosslinking, the crosslinked particles were separated from the suspension by centrifugation and then washed several times by centrifuging/resuspending in THF and ethanol, respectively, and then dried in vacuum at room temperature to obtain a light gray powder.

2.2.4. *Polymeric Nanocapsules*

The synthesis of hollow polymeric nanoparticles is schematically represented in Scheme 1. The crosslinked nanoparticles (0.2 g) were first suspended in THF. Then 24% aqueous HF solution (5 mL) was added into the suspension. The reaction mixture was stirred at room temperature for 12 h to etch the silica cores completely, after which the particles were collected by centrifuged, and then washed several times by centrifuging/resuspending in THF and ethanol to remove all the unreacted HF. The ultimate nanocapsule was dried under vacuum to give as a light gray powder.

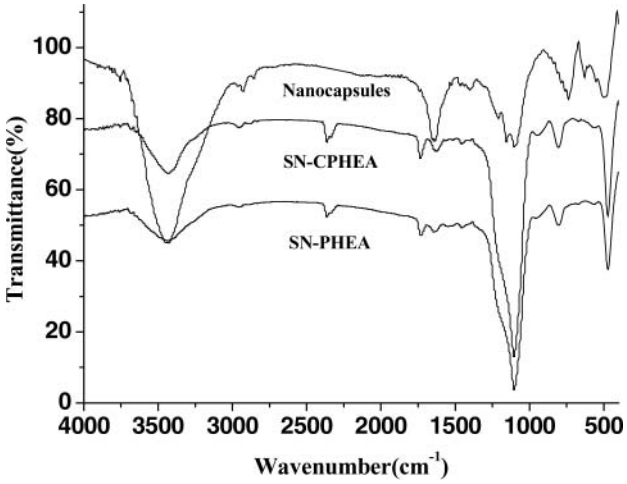


Fig. 1. FT-IR spectra of the SN@PHEA particles, SN@CPHEA particles and nanocapsules.

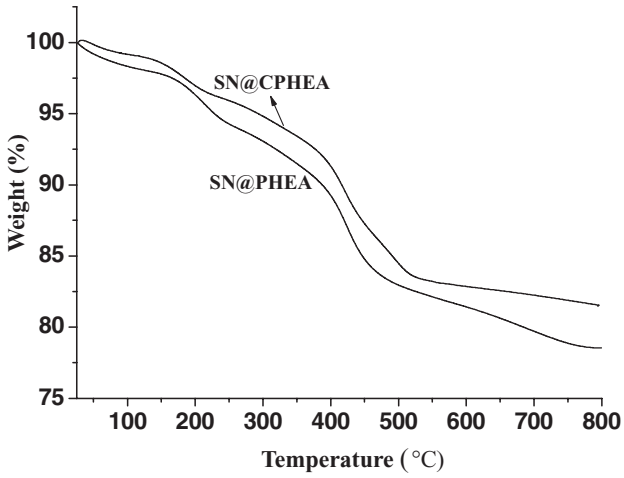


Fig. 2. TGA curve of SN@PHEA nanoparticles and SN@CPHEA nanoparticles.

2.3 Characterizations

Nicolet Sateellite Fourier infrared spectrometer was used for the Fourier transform infrared (FT-IR) spectroscopy analysis in the range of 400–4000 $cm^{-1}$with the resolution of 4 cm^{-1}. The KBr pellet technique was adopted to prepare the sample for recording the IR spectra. Thermogravimetric analysis (TGA) was performed with a PYRIS Diamond TG-DTA High Temp1150 at a scan rate of 10°C $min^{-1}$from room temperature to 800°C in N_2atmosphere. The morphologies of the polymer grafted silica nanoparticles and the polymeric nanocapsules were characterized with a JEM-1200 EX/S transmission electron microscope (TEM). They were dispersed in THF in an ultrasonic bath for 5 min, and then deposited on a copper grid covered with a perforated carbon film.

3 Results and Discussion

A 'core-first' strategy has been applied to synthesize the hollow nanospheres in the present work. Firstly, the 2-bromopropmide groups (about 0.5 mmol/g silica nanoparticles) were immobilized onto the surfaces of the silica nanoparticles by the bromoacetylated of the surface amino groups of AP-SN with bromoacetylbromide (23). Subsequently, the poly(2-hydroxyethyl acrylate) was grafted from the surfaces of the SiO_2nanoparticles by atom transfer radical polymerization (ATRP).

The FT-IR spectrum of the prepared SN@PHEA nanoparticles was shown in Figure 1. The absorption band in the range of 3100 and 3600 cm^{-1} is due to the stretching vibration of O-H, and the absorption at 1735 cm^{-1} ascribed to the C=O stretching vibration of esters is also found for the poly(HEA)-grafted nanoparticles. These FT-IR spectra provided supportive evidence that poly(2-hydroxyethyl acrylate) polymer chains were successfully grafted onto the SiO_2 nanoparticles surface. Typical TGA curve for the SN@PHEA particles was depicted in Figure 2, it showed a weight loss of about 15.3 % at 800°C.

Then the hydroxyl side-groups of the polymer grafted SiO_2nanoparticles (SN@PHEA) were crosslinked with hexamethylene diisocyanate (HDI) (Sch. 1). The absorption at 1640 cm^{-1} ascribed to the -NHCOO- stretching vibration of carbamate was also observed. Typical TGA curve for the crosslinked poly(HEA)-grafted SiO_2 nanoparticles (SN@CPHEA pa) was depicted in Figure 2, which showed a weight loss of about 15.7% at 800°C. The FT-IR spectrum and the TGA results provided supportive evidence that the hydroxyl end groups had been crosslinked successfully with HDI.

Finally, the silica templates encapsulated with the crosslinked polymeric material shells were removed by etching with hydrofluoric acid for 12 h at room temperature. The strong absorption bands at 1097 cm^{-1} of the Si-O-Si symmetric stretching mode and the Si-O at 466 cm^{-1} disappeared after the SN@CPHEA was treated with HF (Fig. 1). It indicated that the silica templates had been removed completely by being etched with HF.

The SN@PHEA, SN@CPHEA and hollow structure of the crosslinked polymeric nanocapsules could be observed in the TEM analysis (Fig. 3 (a, b and c)). The nanocapsules with inner diameter of 10–20 nm showed the conglomeration structures (Fig. 3 (c)). It might be succeeded from the conglomeration structures of the polymer grafted silica nanoparticles (24).

Some individual nanocapsules were also found (Fig. 3 (b)). It had the inner diameter of about 40 nm, which were larger than the sizes of the nanocapsules in the aggregation. The most possible reason was the fact that the aggregation of the primary particles via van de Waals interparticle attraction and the aggregation was kept somehow during the preparation of the functional nanoparticles

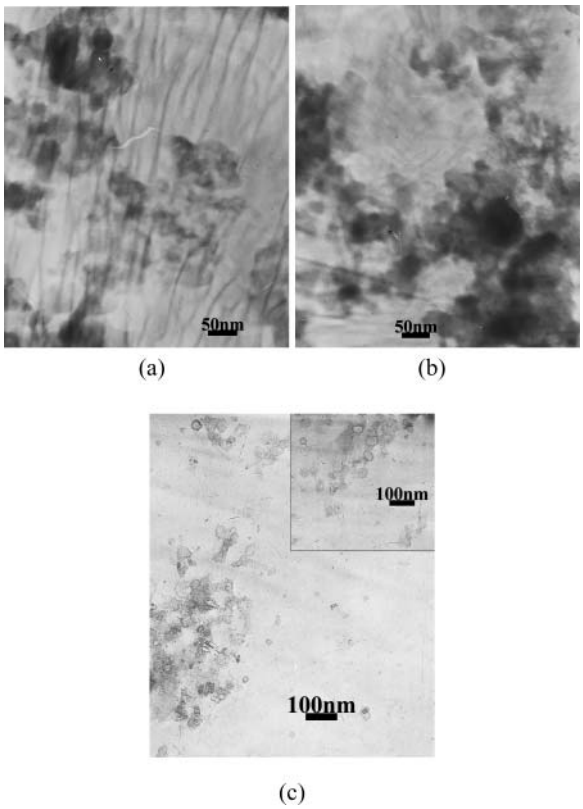


Fig. 3. TEM images of (a) SN@PHEA nanoparticles, (b) SN@CPHEA nanoparticles and (c) crosslinked polymeric nanocapsules.

as well as the following polymerization and purification process (25).

4 Conclusions

A novel procedure was developed for the crosslinked polymeric nanocapsules with diameter of about 20–40 nm using the surface-initiated atom transfer radical polymerization technique from silica templates followed, and then the silica templates were removed by being etched after the poly(2-hydroxyethyl acrylate) had been crosslinked. The method may be used to design the well-defined shell structure and control the shell thicknesses of the polymeric nanocapsules.

Acknowledgments

This project was granted financial support from the National Nature Science Foundation of China (Grant No. 20904017), and the Program for New Century Excellent Talents in University (Grant No. NCET-09-0441).

References

1. Gittins, D.I. and Caruso, F. (2000). *Adv. Mater*., 12(24), 1947–1949.
2. Sukhorukov, G., Fery, A. and Mohwald, H. (2005) *Prog. Polym. Sci*., 30(8–9), 885–897.
3. Wang, Y.J., Bansal, V., Zelikin, A.N. and Caruso, F. (2008) *Nano Lett*., 8(6), 1741–1745.
4. Liu, T.Y., Liu, K.H., Liu, D.M., Chen, S.Y. and Chen, I.W. (2009) *Adv. Funct. Mater.,* 19(4), 616–623.
5. Xu, P.S., Li, S.Y., Li, Q., Van Kirk, E.A., Ren, J., Murdoch, W.J., Zhao, Z.J., Radosz, M. and Shen, Y.Q. (2008) *Angew. Chem. Int. Ed.,* 47(7), 1260–1264.
6. Chia, S.M., Wan, A.C.A., Quek, C.H., Mao, H.Q., Xu, X., Shen, L., Ng, M.L., Leong, K.W. and Yu, H. (2002) *Biomaterials*, 23(3), 849–856.
7. Lawson, G.E., Lee, Y., Raushel, F.M. and Singh, A. (2005) *Adv. Funct. Mater*., 15(2), 267–272.
8. Kreft, O., Javier, A.M., Sukhorukov, G.B. and Parak, W.J. (2007) *J. Mater. Chem*., 17(42), 4471–4476.
9. Kumar, K.R. and Brooks, D.E. (2005) *Macromol. Rapid Commun*., 26(3), 155–159.
10. Meier, W. (2000) Chem. Soc. Rev., 29(3), 295–303.
11. Barari, M., Faridi-Majidi, R., Madani, M., Sharifi-Sanjani, N. and Oghabian, A. (2009) *J. Nanosci. Nanotechnol.*, 9(7), 4348–4352.
12. Cao, Z.H. and Shan, G.R. (2009) *J. Polym. Sci.: Polym. Chem*., 47(6), 1522–1534.
13. Dou, H.J., Jiang, M., Peng, H.S., Chen, D.Y. and Hong, Y. (2003) *Angew. Chem. Int. Ed*., 42(13), 1516–1519.
14. Moughton, A.O., Stubenrauch, K. and O'Reilly, R.K. (2009) *Soft Matter*, 5(12), 2361–2370.
15. Tong, W.J. and Gao, C.Y. (2008) *J. Mater. Chem*., 18(32), 3799–3812.
16. Liu, P., Liu, G.F., Zhang, W. and Jiang, F. (2010) *Nanotechnology*, 21(1), 015603.
17. Donath, E., Sukhorukov, G.B., Caruso, F., Davis, S.A. and Möhwald, H. (1998) *Angew. Chem. Int. Ed.*, 37(16), 2202–2205.
18. Blomberg, S., Ostberg, S., Harth, E., Bosman, A.W., Horn, B.V. and Hawker, C.J. (2002) *J. Polym. Sci.: Polym. Chem*., 40(9), 1309–1320.
19. Fu, G.D., Shang, Z., Hong, L., Kang, E.T. and Neoh, K.G. (2005) *Macromolecules*, 38(18), 7867–7871.
20. Morinaga, T., Ohkura, M., Ohno, K., Tsujii, Y. and Fukuda, T. (2007) *Macromolecules*, 40(4), 1159–1164.
21. Mandal, T.K., Fleming, M.S. and Walt, D.R. (2000) *Chem. Mater*., 12(15), 3481–3487.
22. Li, P., Zhu, Z.M. and Peng, M. (2008) *J. Mater. Sci.,* 43(16), 5651–5653.
23. Mu, B., Shen, R.P. and Liu P. (2009) *J. Nanosci. Nanotechnol*., 9(1), 484–489.
24. Mori, H., Seng, D.C., Zhang, M.F. and Muller, A.H.E. (2002) *Langmuir*, 18(9), 3682–3693.
25. Mu, B., Shen, R.P. and Liu P. (2009) *Nanoscale Res. Lett*., 4(7), 773–777.