Synthesis and Characterization of Silica Based Functional Nanoparticles for Multi-Purpose Applications

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Abstract— Monodispersed silica nanoparticles with an average size of 10nm in diameter were synthesized by Stöber method from tetraethyl orthosilicate (TEOS), ethanol and deionized water in the presence of basic amino acids (L-Lysine/L-Arginine) as catalyst. The resulting nanoparticles were investigated by Scanning Electron Microscopy (SEM), X-Ray Diffraction (XRD), Dynamic Light Scattering (DLS), BET (Brunauer-Emmett-Teller) surface area and average pore size.

In recent years, synthesis of monodisperse nanoparticles has one of the most active areas in bioanalysis and biotechnological applications because of their unique optical properties, high surface to volume ratio and other size dependent qualities [1]. The preparation of monodisperse silica colloidal particles by controlled hydrolysis of silicon alkoxides has been extensively studied since Stöber et al first successfully synthesized spherical SiO2 colloidal particles using this technique [2]. These studies have revealed that the size and size distribution of silica particles strongly depend on reaction conditions such as TEOS/ H2O/ NH3 concentration ratios, solvent type and temperature [2]. The size of nanoparticles plays an important role in determining their properties as well as their usefulness in bioapplications especially nanoparticles of a 1-100nm size have broad applications in biology such as biolabeling, imaging, drug delivery, separation and optical sensing [3].

In this work, we synthesized spherical and monodisperse silica nanoparticles with the hydrolysis and condensation reactions of tetraethyl orthosilicate (TEOS) as a silica source were carried out in the presence of L-Lysine/ L-Arginine by the well known preparation method, Stöber method. Lysine, which is the basic amino acid, was used as a catalyst instead of ammonium hydroxide.

We first investigated the influence of the amino acids on the formation of silica nanospheres (SNSs). Among 20 types of essential amino acids in protein, L-Lysine, L-Histidine and L-Arginine are categorized as basic amino acids. When L-Lysine/L-Arginine was used, the obtained SNSs were similar structural properties with the size of 10nm and 15nm, respectively.

We next studied the influence of the amount of L-Lysine/L-Arginine on the formation of the SNSs and yield. We synthesized SNSs by using the L-Lysine in the molar range of 0.1- 8. It is observed that both particle size and yield increased, by increasing the amount of L-Lysine.

In addition, we examined the influence of the temperature on the formation of SNSs and particle size. In the range of 20°C- 100°C, we synthesize SNSs in the presence of L-Lysine. It is demonstrated that the size of the silica spheres increases with the increasing of the temperature. The particle size was found 5nm in the 20°C experimental temperature and was 40nm in the 100°C.

Moreover, stirring rate and without organic solvent effects also investigated. It is found that the size of the SNSs decreases with increases of the stirring rate in the range of 0-1000rpm. Besides, well-ordered SNSs are synthesized without using octane. However, it is observed that TEOS is hydrolyzed at faster rate without octane, which tends to nucleate more particles and leads to smaller average particle sizes with lower reproducibility.

Furthermore, we studied the dye incorporation (core-shell) into these silica nanospheres by using Rhodamine B isothiocyanate (RBITC) which is an amine reactive fluorescent dye. The release of the dye was controlled both dialysis and centrifugation process. It is observed that using small amount of dye is more appropriate than larger amount of dye. These dye-doped silica nanospheres could be use such as biomarkers in biological applications.
We next discuss the preparation of structurally well-defined polymer modified SNSs, where the polymer is grafted onto the surface. In addition, the surface of the polymer grafted SNSs can be modified to contain amine, sulfide, carboxylate groups, antibodies or binding DNA strands to directly can be used in bioanalytical applications such as biomarker, biosensors for early tumor diagnosis or targeted drug delivery into cells for cancer treatment. This will be done before the polymerization step and will allow studying the particles also by means of fluorescence experiments (especially important when looking at their interaction with membranes).

In summary, we concluded that L-Lysine (basic amino acid) can be used as a catalyst to synthesize well-ordered, monodisperse SNSs which have two amino groups that are indispensable for the 3D well-ordered arrangement of the silica nanospheres. We have demonstrated dye-doped SNSs which can provide us a new approach in bionanotechnological applications, such as optical tracking and monitoring, which is useful tools for studying drug delivery and drug–cell interactions such as biomarkers.