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MINI-REVIEWS

Green and sustainable synthesis of silica nanoparticles

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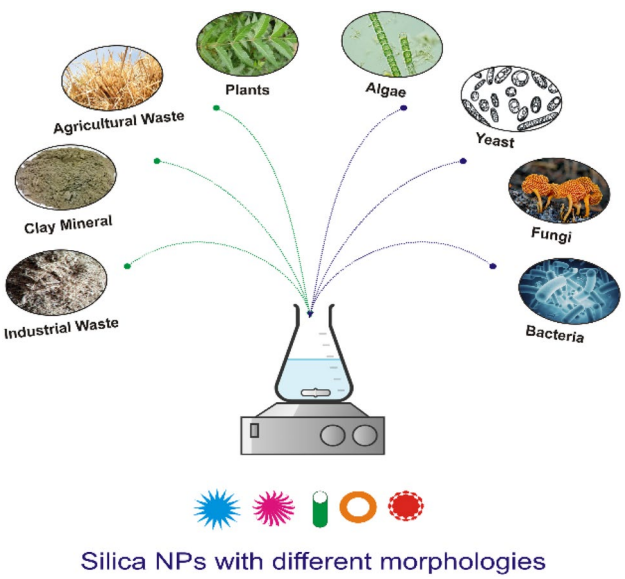
Abstract

Silica nanoparticles (SiNPs) have shown a wide range of applications in various technological fields. It is due to their unique properties such as biocompatibility, stability, tunable pore size, high surface area and surface reactivity. The ease of surface functionalization of SiNPs further extends their applications in biomedicine, targeted drug delivery and biosensing applications. Most of the works on SiNPs are focused on their synthesis by chemical methods for different applications. However, SiNPs can be prepared by green synthetic protocols that utilize plants, agriculture waste, industrial waste, fungi, bacteria, yeast, clay/mineral, worms, actinomycetes, etc. The green and sustainable methods offer distinctive encouraging features to produce nanomaterials with desired properties. The green synthesis of silica nanoparticles is an important area of research having considerable potential for further future developments. In this mini review, collective information on current green approaches for the synthesis of SiNPs is presented. The various green methods of synthesis for SiNPs are discussed with examples from the literature. The future challenges and expected advances are also pointed out which will decide the direction of research in this field.

Graphic abstract



Keywords Silica nanoparticles · Silicon dioxide · Green synthesis · Plant extracts · Microorganisms

Introduction

Silica nanoparticles (SiNPs) and porous SiNPs have shown wide range of applications in various technological fields ranging from nanocomposites and ceramics to diagnosis tools and drug delivery [1]. Stöber et al. synthesized silica nanoparticles in 1962 by using tetraethyl orthosilicate (TEOS) as the silica precursor, ethyl alcohol and water as solvents and ammonia as an alkaline catalyst [2]. The scheme of synthesis of SiNPs by Stöber's method using TEOS as silica source is shown, in Fig. 1. Then onwards, there are several reports in the literature about the synthesis of SiNPs. The synthesis was done by modifying the reaction conditions, varying the base or catalyst and by using different precursors [3, 4]. The nanoparticles can be synthesized by "top-down" and "bottom-up" approaches [5]. The bottom-up methods use various hazardous chemicals and expensive processes that can cause potential environmental and biological hazards [6]. The SiNPs can also be synthesized by different physical and chemical methods, such as sol–gel synthesis [7], chemical vapour condensation [8], flame synthesis [9], laser ablation [10], reverse microemulsion synthesis, etc. [11].

However, these methods have some disadvantages. For instance, sol–gel and hydrothermal synthesis methods need costly raw materials and they also need very high-temperature furnace or heating devices [12]. The chemical vapour

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