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# Biodegradation-tunable mesoporous silica nanorods for controlled drug delivery

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ABSTRACT

Mesoporous silica in the forms of micro- or nanoparticles showed great potentials in the field of controlled drug delivery. However, for precision control of drug release from mesoporous silica-based delivery systems, it is critical to control the rate of biodegradation. Thus, in this study, we demonstrate a simple and robust method to fabricate "biodegradation-tunable" mesoporous silica nanorods based on capillary wetting of anodic aluminum oxide (AAO) template with an aqueous alkoxide precursor solution. The porosity and nanostructure of silica nanorods were conveniently controlled by adjusting the water/alkoxide molar ratio of precursor solutions, heat-treatment temperature, and Na addition. The porosity and biodegradation kinetics of the fabricated mesoporous nanorods were analyzed using $N_2$ adsorption/desorption isotherm, TGA, DTA, and XRD. Finally, the performance of the mesoporous silica nanorods as drug delivery carrier was demonstrated with initial burst and subsequent "zero-order" release of anti-cancer drug, doxorubicin.



## 1. Introduction

Mesoporous silica is an attractive biomaterial because of their stable pore structure based on their high regularity, high surface to volume ratio, biocompatibility, biodegradation, and control of pore size at nanoscale [1–3]. Recently, mesoporous silica nanoparticles have drawn much attention as promising drug carriers in controlled drug delivery since it biodegrades in a controlled manner. In particular, biodegradable mesoporous silica has been used as drug carriers to store unstable proteins or poorly-soluble drugs for sustained and controlled delivery to target tissues [4–8]. The biodegradation and drug loading capacity of mesoporous silica were reported to vary according to their porosity and pore size [4,9–12]. Thus, modulation of the porosity and pore size of mesoporous silica can enable robust control of drug release kinetics from drug delivery system based on mesoporous silica.

Existing fabrication processes for mesoporous silica nanoparticles include particle growth techniques using laser ablation and atomic layer deposition, anodizing, growth in liquid phase, electrolytic plating, and chemical vapor deposition (CVD) using supports [9–11]. More recently, a silicon wafer etching process has been developed to fabricate porous silicon nanowires with biodegradability for controlled drug delivery [4]. However, those approaches are expensive and time consuming. It is also difficult to control the porous structure that determines the biodegradation rate of mesoporous silica carriers. As another way to control the silica polymer network or pore structure of silica ceramics, sol–gel processes using tetrarethylorthosilicate ($Si(OC_2H_5)_4$) (TEOS) have been explored. The TEOS-based sol–gel processes were focused on controlling pore morphology of silica structure by change of water quantity [1,13–15], change of the rates of hydrolysis and condensation reaction [16], stepwise addition of ingredients with time intervals [17], and addition of acidic and basic catalysts [1,17,18].

In this study, we propose an AAO template-based sol–gel process that allows for diverse control of the compositions and processes to "conveniently tune" the porosity and biodegradability of mesoporous silica nanorods (NRs) (Fig. 1). In particular, we report significant change in biodegradation rates of fabricated NRs by controlling their porosity and heat-treatment temperature as well as Na addition. Porosity apparently increases the corrosion surfaces of amorphous silica pore walls inside NRs, which are susceptible to water-based corrosion attack, and, therefore, is a very effective variable to control biodegradability. We increased the porosity of the fabricated NRs up to about 47% by controlling water amount of the precursor solution and annealing temperature. Effect of both water content in precursor solutions and heat-treatment on the microstructure, porosity, and crystallinity of NRs was also monitored to understand the biodegradability of mesoporous NRs. Furthermore, sodium (Na) at the maximum amount up to 5 mol% was added to precursor solutions to fabricate Na-doped mesoporous NRs (NaNRs) with accelerated biodegradation. Such incorporation of Na into amorphous silica network was expected to disrupt siloxane bond (Si–O–Si) by forming $Na_2O$ ending groups. This can lead to

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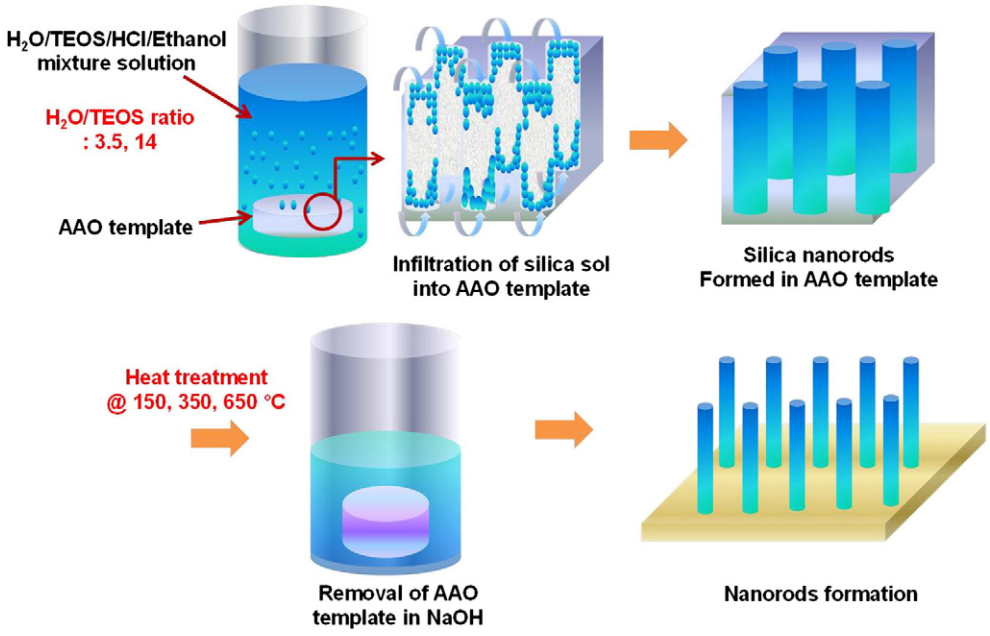


**Fig. 1.** Schematic diagram of silica sol-based nanorod fabrication using AAO template.

seriously reduced chemical stability of NRs and faster breakdown of silica structure. Fabrication of NaNRs was demonstrated and their accelerated biodegradation dependent on Na content was also confirmed. Finally, drug release performance of NRs and NaNRs using anti-cancer drug, doxorubicin, was demonstrated and discussed.

## 2. Materials and methods

### 2.1. Synthesis of mesoporous NRs

Nanorod samples with different water contents in precursor solutions were prepared to control the pore size and structure of NRs

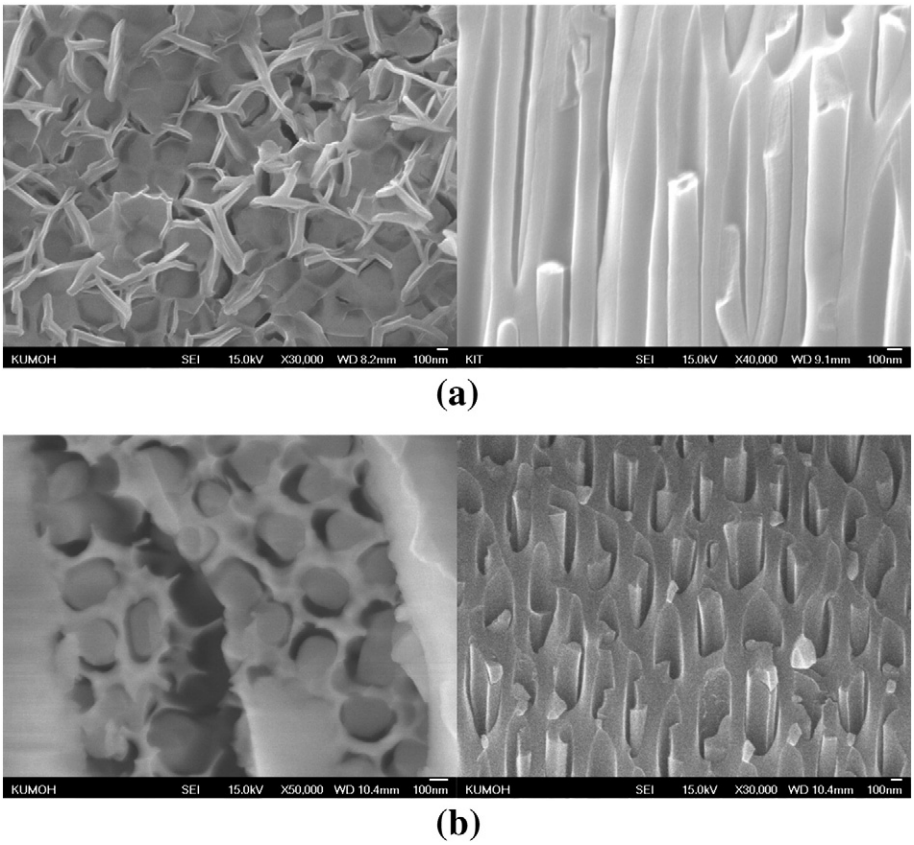


**Fig. 2.** FE-SEM images of (a) NR1 and (b) NR2 formed in AAO templates.