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# Fabrication method of parallel mesoporous carbon nanotubes

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ABSTRACT

A facile approach to prepare parallel mesoporous carbon nanotubes fabricated from an anodised aluminum oxide (AAO) template loaded with mesoporous silica by combining sol–gel and chemical vapor deposition (CVD) techniques is presented. The carbon nanotube walls that grow during CVD process copy the mesoporous structure of silica without removing the surfactant. The mechanism of formation of mesoporous carbon nanotubes was also studied. The technique results in a simple and efficient manner to produce parallel mesoporous carbon nanotubes exhibiting high specific surface area.



## 1. Introduction

Among all investigated materials, ordered mesoporous materials (OMM) and carbon nanotubes (CNTs) gained a tremendous attention due to their fantastic properties since their first discovery in 1992, and 1991, respectively. A combination of large specific surface area and high size- and shape-selectivity makes OMM a great candidate for applications such as catalysis, adsorption, and separation [1].

CNTs exhibit extraordinary mechanical, electrical and thermal properties that make them promising for many applications, such as in structural materials, electronic and optical devices, supercapacitor electrodes and hydrogen storage [2]. Several direct methods have been developed for the synthesis of CNTs, including arc-discharge, laser ablation, and chemical vapor deposition [3]. Recently, templating methods have been developed to synthesize CNTs by carbonization of either polymer or pre-organized disclike molecules in porous anodic aluminum oxide (AAO) membranes [4]. Being carbon based, such structures offer significant benefits ranging from electrical conductivity to enhanced chemical functionality and stability as compared to their silica mesophase analogues.

Among all the applications, the use of CNTs as a catalyst support seems to be one of the more promising fields with large economical implications. The results published to date [5] seem to indicate that nanostructured carbon can represent a new class of advanced materials for catalytic applications allowing the modification of the reaction rate and of the final product selectivity rendering the process more environmentally benign because of the interaction between metal nanoparticles and graphic carbon. CNTs used as catalyst supports induce peculiar activity and selectivity in several catalytic reactions such as in the hydrogenation of olefins [6] and nitrobenzene into aniline [7], selective hydrogenation of the C=C bond in an-unsaturated aldehyde [8].

It was also found that the tubular morphology and the high aspect ratio of CNTs could induce a confinement effect on the gas or liquids trapped inside the tube leading to completely different physical behavior when compared to conventional bulk material. Several reports recently dealt with the behavior of fluid trapped inside these high aspect ratio tubular materials [9].

In addition, many experimental results have shown that the small size of the carbon nanostructured materials significantly contributes to the final catalytic performance of the system since catalytic reactions are governed by the phenomena of mass and heat transfer between the catalyst particles and the reactants. It is expected that reducing the catalyst size can make the reaction faster during the catalytic process.

However, multi-walled carbon nanotubes (MWNTs) have a low specific surface area, what constitutes a limitation for applications such as those regarding gas, energy storage and catalyst support. A combination of the advantages of mesoporous materials and tubular CNTs to form CNTs with fine mesochannels with a size of about a few nanometers is of much importance and would provide wider applications in nanodevice fabrication, biomacromolecule

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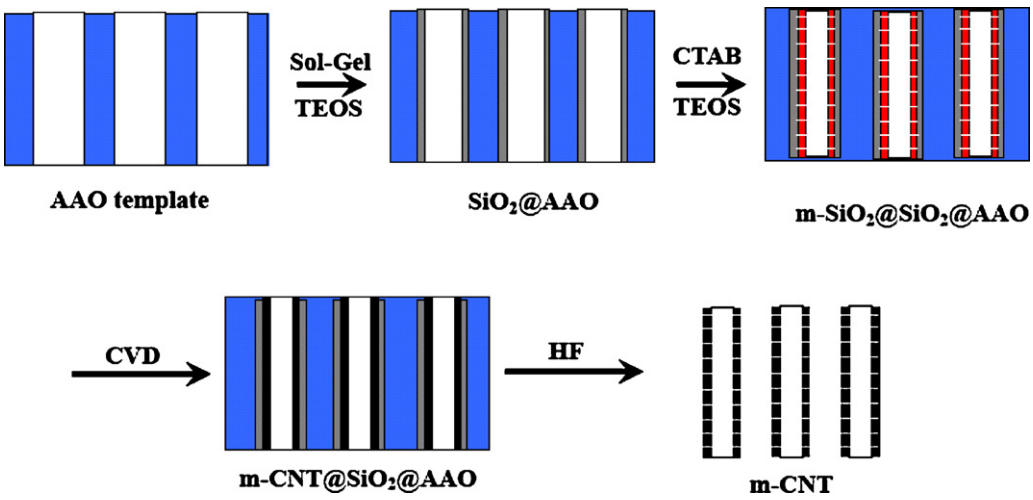


**Scheme 1.** Schematic of the synthesis steps for mesoporous CNTs.

separations and more extensive applications in many other fields. In this sense, nowadays there is great interest to obtain high specific surface area MWNTs to improve the performance of these materials. Up to now, only several research groups have reported the synthesis of mesoporous CNTs [10].

In this article, we report the synthesis of MWNTs with a mesoporous wall from an AAO template through a simple sol–gel and CVD method. The diameter of formed MWNTs is in the range of 200–270 nm, in agreement with the pore sizes of the used AAO template. The walls forming the MWNT have mesochannels with a channel size of about 1.15 nm. The purified CNT have high specific surface area (108 $m^2/g$), which may serve as a new and efficient mold and find wider applications in nanodevice fabrication, catalyst support and bio-macromolecule separation.

## 2. Experimental

### 2.1. Materials

AAO template was purchased from Waitman Company (200 nm). Tetraethyl orthosilicate (TEOS) and cetyltrimethyl ammonium bromide (CTAB) were bought from Aldrich. These reagents were used as received.

### 2.2. Synthesis of mesoporous carbon nanotube

Initially, a silica sol–gel precursor was prepared by adding 50:5:1 ratio of absolute ethanol:tetraethoxysilane (TEOS):1 M HCl, respectively. The mixture was allowed to hydrolyze for 1 h at room temperature. An AAO template (average pore diameter 200 nm,

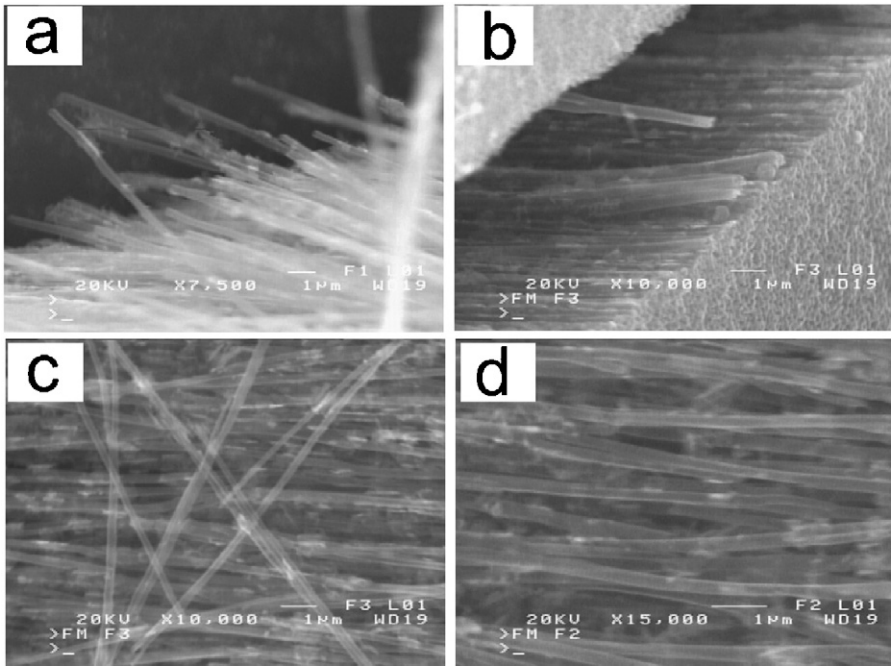


**Fig. 1.** SEM images of parallel CNT composed of mesoporous walls.