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ORIGINAL ARTICLE

# Hierarchically macroporous silver monoliths using Pluronic F127: Facile synthesis, characterization and its application as an efficient biomaterial for pathogens

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**KEYWORDS**

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**Abstract** Herein we report the facile synthesis of three dimensional macroporous (MP) silver monoliths serving as intelligent biomaterials against Gram negative (*Escherichia coli, Salmonella typhimurium*) and Gram positive (*Bacillus subtilis*) bacteria with more efficacy against Gram negative bacteria. The macroporous silver monoliths were examined by Fourier transform infra red (FTIR) spectroscopy, thermogravimetric analysis (TGA), X-ray diffraction (XRD) study, field emission scanning electron microscopy (FESEM), energy dispersion X-ray spectroscopy analysis (EDX) and Brunauer–Emmet–Teller (BET) adsorption technique. From the antibacterial activity results, it was concluded that macroporous silver monoliths can serve as efficient disinfection agents. The enhanced antibacterial properties of macroporous silver monoliths was possibly due to high surface free energy of the surface $Ag^{+}$ atoms leading to cell membrane damage followed by cell death.



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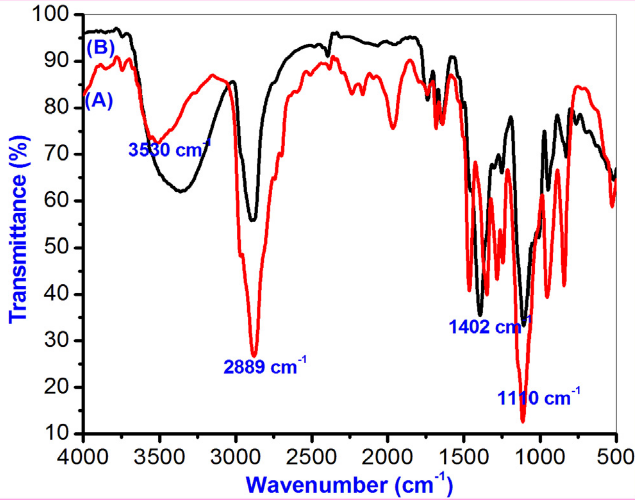


**Figure 1** Fourier transform infrared spectroscopic (FTIR) studies of as prepared $AgNO_3$/F127 composite gel carried out before calcination. (A) pure Pluronic F127, (B) $AgNO_3$/F127 composite gel.

## 1. Introduction

Metallic porous materials are of great interest for heterogeneous catalysis, sensor technology, electrochemical supercapacitors, fuel cell electrodes, bio-filtration capability, medicine, photonic crystals, chemical separations, and photocatalysis [1–8]. Among these metallic porous materials, silver is the dynamic and highly efficient promising material for various biomedical applications because of its environmentally benign and eco-friendly nature [9–17]. The non-toxicity and bactericidal activity of silver materials makes it an efficient choice for multiple roles in the medical field including in the formulation of dental resin composites; as a bactericidal coating in water filters; as an antimicrobial agent in air sanitizer sprays, in coatings of medical devices; detergents, socks, wet wipes, toothpastes, soaps, shampoos, pillows, respirators, washing machines, and many other consumer products; as bone cement; and in many wound dressings to name a few [9–17].

There are many synthetic routes that have been explored to fabricate porous silver based materials for many bio-medical applications [18,19]. Among the synthetic routes include: electrochemical [20], sonochemical [21], sol–gel [22–24], microwave [25], radiation assisted process [26], photochemical [27] and currently by green chemistry synthesis [28,29]. Although porous noble metal materials have been used extensively in these potential applications still the synthesis of hierarchical porous noble metal materials is challenging despite significant progress in preparing micro-meso and macrostructured porous materials of metal and metal oxides.

Here, we have synthesized hierarchically macroporous silver monoliths using Pluronic F127 as a reducing agent via modified sol gel route without using any acidic or basic medium i.e. "green" approach and the most significant advantage of the reported method is that conditions of high temperature, pressure, and toxic chemicals are not required in the synthesis protocol. Furthermore, we examined the bactericidal activity of as synthesized metallic porous silver monoliths against Gram negative and Gram positive pathogens (*Escherichia coli*, *Salmonella typhimurium* and *Bacillus subtilis*), comparing its properties with that of standard antibiotic (amoxicillin) by using Kirby–Bauer disk diffusion method.

## 2. Experimental

### 2.1. Synthesis of macroporous metallic silver monoliths

In a typical synthesis, 2.0 g of silver nitrate (50 wt.%, BDH) in 2.0 g of ultrapure water (50 wt.%) was added to 2.0 g of soft template Pluronic F127 (polyethylene oxide – polypropylene oxide – polyethylene oxide, $[(EO)_{106}\ (PO)_{70}\ (EO)_{106}]$, 14.81 wt.%, Aldrich) in 11.50 g of ultrapure water (85.19 wt.%) and stirred vigorously. The gel was stirred at room temperature for 1 h to form the paste which gradually became dark in color. The resulting gel was aged for 48 h at room temperature

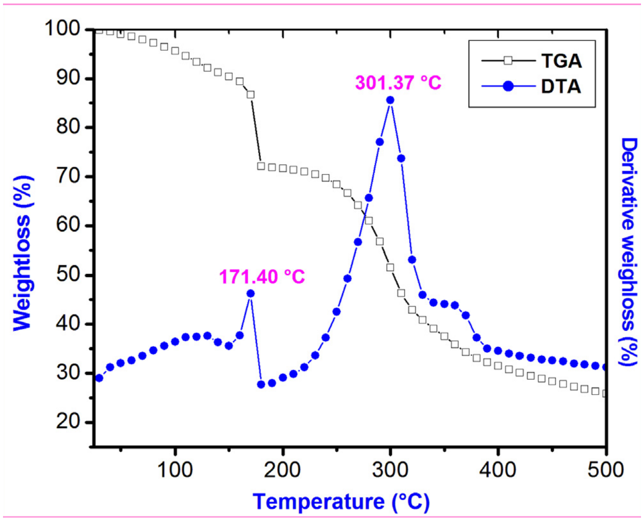


**Figure 2** TGA-DTA profile of $AgNO_3$/F127 composite gel.

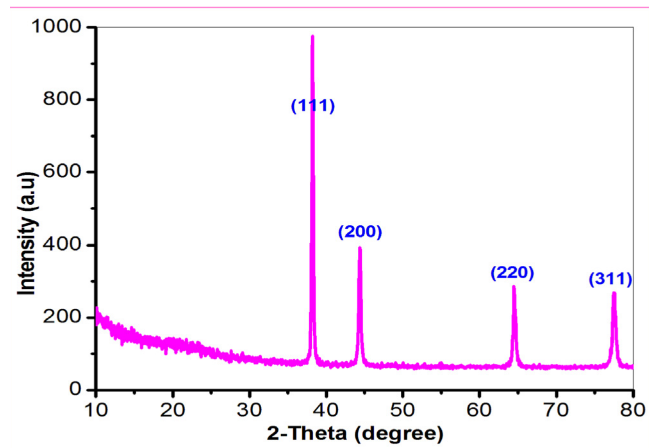


**Figure 3** XRD patterns of macroporous silver particles prepared by using F127 as a reducing agent obtained after the calcination of $AgNO_3$/F127 composite gel.