Electrodeposition of AuPt Alloy Nanostructures on a Biotemplate with Hierarchically Assembled M13 Virus Film Used for Methanol Oxidation Reaction

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ABSTRACT
Herein, we report an electrode surface with a hierarchical assembly of wild-type M13 virus nanofibers (M13) to nucleate the AuPt alloy nanostructures by electrodeposition. M13 was pulled on the electrode surface to produce a virus film, and then a layer of sol–gel matrix (SSG) was wrapped over the surface to protect the film, thereby a biotemplate was constructed. Blending of metal binding domains of M13 and amine groups of the SSG of the bio-template were effectively nucleate and directed the growth of nanostructures (NSs) such as Au, Pt and AuPt alloy onto the modified electrode surface by electrodeposition. An electrocatalytic activity of the modified electrode toward methanol oxidation in alkaline medium was investigated and found an enhanced mass activity (534 mA/mg) relative to its controlled experiments. This bio-templated growth of NSs with precise composition could expedite the intention of new alloy materials with tuneable properties and will have efficacy in green energy, catalytic, and energy storage applications.

Keywords : Bio-template, Metal Electrodeposition, M13 Virus, Methanol Oxidation, Surface Functionalization

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1. Introduction

Bio-templates assisted synthesis of inorganic nanomaterials is attracting the generous interest in the contemporary nanoscience research due to its unlimited and potential applications in the industrial and medical fields [1-3]. In the bio-template, biomolecule is a key component and it is widely exploited to assemble and formulate variety of nanomaterials on its bio-functional domains [4,5]. In comparison with the conventional chemical methods, bio-template assisted synthetic approaches have various benefits for making the nanoscale materials. Such benefits arise from the distinctive functionalities of biomolecules [3]. Especially, carboxyl and amine groups’ functionalized biomolecules can facilitate the effective interaction between the biomolecules and the nanomaterial precursors [6]. In addition, to maintain the charge neutrality and express their specific affinities; biomolecules do prefer to assemble and align in a specific outline. Such outline can be used as a scaffold to derive the functional nanomaterials. Moreover, mimicking a nature based bio-template model system to derive technologically important nanoscale materials become a current area of research in recent years [7]. So, the bio-templating approaches could provide absolutely distinctive, less expensive routes for nanomaterials synthesis [8,9]. M13 bacteriophage is a filamentous virus that infects bacteria host cells and having a dimension of 860 nm in length and 6.5 nm in diameter [10,11]. Large-scale production of M13 bacteriophage is a feasible process since, infected bacteria is the starting material (E. coli) and is highly abundant in nature. The schematic structure of the wild-type M13 bacteriophage (M13) used in this study is given in Fig. 1. The helically arrayed major coat protein capsid; pVIII is responsible for the filamentous body of the M13. Head of the filamentous body consists of five copies of pI\(\text{X}\) and p\(\text{VII}\)
proteins and they are responsible for the rounded capsids. Tail portion consists of remaining minor coat proteins of pIII and pVI and they are responsible to infect the host bacteria (E.coli). The functionality of M13’s subunit proteins has a good binding affinity and specificity towards target molecules. Hence, M13 based bio-templates might be suitable bio-alternative to traditional material-based templates to obtain the functional nanoscale materials. Deriving the templates on solid surfaces, suitable surface coating techniques need to be applied. A pulling method, a kind of dip coating method, has been usually employed to construct the M13 multilayer biofilms on solid surfaces. [12].

Extensive research has shown the utility of gold (Au), platinum (Pt) and AuPt alloy nanoparticles (NPs) as the highly active and stable catalytic materials for various applications [13-16]. In particular, AuPt NPs are of widely studied as catalysts for fuel cells, hydrogenation and oxidation of organic compounds, degrading the environment pollutants and electrochemical oxidation of small organic molecules which are suitable for fuel cell applications [10]. Hence, to decrease the usage of expensive Pt loading in the catalytic systems, synthesis of AuPt core/shell or alloy nanostructures (NSs) with the controlled structural features are highly desired [16]. A substantial task in this research is the development of synthetic approaches which are capable of producing uniform and structurally tuned core/shell or alloy NSs with controlled size, morphology and composition for practical electrochemical applications. Direct methanol fuel cell (DMFC) operating in alkaline medium offers the less corrosive environment for the metal based catalysts and obviously exhibits improved reaction kinetics as well, and can proceed at lower potential too [16,17]. Here we report a facile fabrication technique to obtain the bio-templated AuPt alloy NSs via electrodeposition and their electro-catalytic activity of MOR in alkaline medium was investigated. Present fabrication approach has the following advantages; (i) a bio-template with a M13 film prepared by the pulling method offer effective nucleation and growth of AuPt NSs from their corresponding precursors, (ii) integration of SSG into this bio-system, protects M13, assist and regulate the nucleation and growth of AuPt NSs, (iii) distinctive AuPt alloy NSs can be synthesized where the porosity, morphology and loading amount can be finely tuned by the pulling time, mode of introducing SSG, and concentration of the metal precursors.

2. Experimental

2.1 Materials

Gold(III) chloride hydrate (HAuCl₄·3H₂O), chloroplatinic acid hexahydrate (H₂PtCl₆·6H₂O) and N₁-(3-trimethoxysilylpropyl)diethylenetriamine (silane monomer used to prepare the SSG; silicate sol−gel matrix) were received from Sigma-Aldrich. Methanol (MeOH) was obtained from DaeJung chemicals. Indium tin oxide (ITO, dimension 3 × 1 cm) and its modified forms were used as working electrodes. Pt wire was used as a counter electrode, and Ag/AgCl (in 3 M NaCl solution) was used as a reference electrode. Electrochemical experiments were conducted in a single-compartment three-electrode cell using an Ivium Technologies electrochemical workstation. Nitrogen (N₂) was bubbled for 30 min prior to each experiment.

2.2 Wild-type M13 Virus Preparation

Wild-type M13 virus (M13) was grown and purified by following the standard biochemical protocols [10, 11]. Briefly, one colony of E. coli XL-1 blue was grown in 3 mL of LB media to mid log phase (E. coli XL-1 blue culture) and infected with 10 μL of wild-type M13 virus. The culture was incubated at 37°C with shaking for 12 h and then centrifuged to remove E. coli. The M13 was collected by PEG/NaCl (20% PEG and 2.5 mol/L NaCl) precipitation and reconstituted in Tris-buffered saline (10 mM). The typical yield was ~20 mg/L of M13. The final concentration was determined spectrophotometrically using an extinction coefficient of 3.84 cm²/mg at 269 nm.

2.3 Preparation of SSG

Homogeneous 1 mM SSG solution was prepared
by adding 10 µL of 1 M SSG silane monomer (N\(^1\)-(3-trimethoxysilylpropyl)diethylenetriamine) into 10 mL of aqueous solution under vigorous stirring and the stirring was continued for another 60 min.

### 2.4 Fabrication of Modified Electrodes

M13-assembled films were constructed [18] with a commercial syringe pump (KD Scientific, USA). The built-in software of the syringe pump was used to adjust pulling speeds. A cleaned ITO electrode was immersed in a M13 solution (0.1 mg/mL), subsequently subjected to the pulling method for 5 or 10 or 20 h. Subsequently, after the immersion period the ITO electrode was taken out and carefully rinsed and dried with N\(_2\). In the next step, 50 µL of the pre-formed SSG solution (1 mM) was carefully drop-cast on the M13-pulled ITO surface and allowed to dry in an incubator at 37°C for 2 h. The dried electrode was soaked for 10 min in an electrolyte solution (mixture of 1.5 mM H\(_2\)PtCl\(_6\) and HAuCl\(_4\) or 3 mM H\(_2\)PtCl\(_6\) or 3 mM HAuCl\(_4\) in 0.5 M H\(_2\)SO\(_4\)) for electrodeposition of AuPt or Pt or Au NSs by applying a potential of -0.2 V (Ag/AgCl) for 500 s. Fabricated electrodes were denoted as ITO/M13/SSG/AuPt or ITO/M13/SSG/Pt or ITO/M13/SSG/Au. As a controlled experiments, mixture of M13+SSG, M13, SSG and only ITO surfaces were used for the electrodeposition of AuPt and fabricated electrodes were denoted as ITO/M13+SSG/AuPt, ITO/M13/AuPt, ITO/SSG/AuPt and ITO/AuPt, respectively.

### 2.5 Electrochemical Studies

The electrochemically active surface areas (ECSA) of fabricated electrodes were derived by using the curve-fitting tool of the MATLAB software package by integrating “Q” of hydrogen adsorption curve. Prior to curve fitting the non-faradaic current was eliminated. To obtain the hydrogen adsorption curve, cyclic voltammograms (CVs) were recorded in 0.5 M H\(_2\)SO\(_4\) solution (saturated with nitrogen) at a scan rate of 50 mV/s from -0.4 to 1.2 V. The methanol oxidation reaction (MOR) was studied by recording CVs in 0.1 M KOH and 0.1 M CH\(_3\)OH solution at a scan rate of 50 mV/s from -1 to 0.6 V. Furthermore, stability of the fabricated electrodes was assessed by recording a continuous cycling test and an amperometric i-t curve under an applied potential of -0.3 V for 1500 s. The mass of the Pt was calculated as follows; at first current was monitored during deposition and charge (Q) was used to estimate specific mass (M) of Pt using the eq 1.

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M = \frac{Q \times MW}{(n FA)}
\]

where ‘M’ is specific mass after electrodeposition, ‘Q’ is charge consumed for electrodeposition, ‘MW’ is the molecular mass of Pt, ‘n’ is number of electrons (4) transferred for electrodeposition, ‘F’ is Faraday constant and ‘A’ is geometrical area (0.44 cm\(^2\)) of the electrode (‘O’ ring).

### 3. Results and Discussion

#### 3.1 Surface characterization of the modified electrodes

Both plant and animal viruses have been previously documented for the interaction, assembly and growth of functional nanoscale materials. As represented in Fig. 1, capsid proteins of the M13 nanofibers can facilitate the interaction between peptides present on M13 surface and nanomaterial precursors hence; they are ideal candidates for nanomaterial fabrication [19-21], and for drug and gene delivery, and tissue engineering fields [22]. In this study, bio-mineralization of Au and Pt metal precursors was achieved through electrodeposition at the fabricated bio-template (M13/SSG); such process would offer the secure electrical pathways by connecting the electrodeposited NSs. On contrary, M13-assisted bio-mineralization by the chemical deposition method, often suffers with the lack of electrical pathways which are essential for fuel cell applications such as DMFCs.

In order to explore the metal precursor nucleating ability of the M13, we have designed three types of bio-template; (i) M13-pulled onto a bare ITO surface (ITO/M13); (ii) M13-pulled from a mixture of M13...
and SSG onto a ITO surface (ITO/M13+SSG); (iii) wrapping a layer of SSG over a M13-pulled ITO surface (ITO/M13/SSG). With these bio-templates, M13 pulling time was varied as 5, 10 and 20 h; more the
pulling time, more number of M13 will be pulled onto the electrode surface; we had encountered a conductivity problem with the 20 h pulled sample hence, it is limited for the further studies. AFM images of the M13-pulled (10 h) surfaces are representing bundles like structures [23,24] and it can be attributed to the presence of M13 attached with the each other’s [25,26] (Fig. 2A-C). Fabricated bio-templates were subjected to the nucleation and growth of AuPt NSs through electrodeposition. After the deposition process, fabricated electrodes were carefully rinsed with DI water and their surface morphology was analysed by SEM studies as shown in Fig. 2. A close inspection reveals that at the ITO/M13 (5 and 10 h) and ITO/M13+SSG (5 and 10 h) bio-templates, AuPt NSs were nucleated and grown well and the particles size is around 1 µm and the particles were well separated with each other (Fig. 2D, E, G and H). On contrary, at the ITO/M13/SSG (5 and 10 h) bio-template, network of AuPt NSs are clearly seen (Fig. 2F and I). In addition, the wrapped SSG acted as a solid support and protects the pulled M13 beneath it and made effective nucleation and growth process [27]. As an impact highly porous and network structures are obtained. Such surfaces are more suitable candidates for the efficient mass transport. Hence, condition optimized to fabricate the ITO/M13-(10)/SSG was 10 h of pulling time, and the similar experimental conditions were applied for the controlled experiments such as depositing mono-metallic Au and Pt NSs and without SSG and the studied SEM images are summarized in Fig. 3. Interestingly, the mono-metallic Au and Pt NSs did not prefer to form network-like structures, instead dendritic and porous plate-like structures (Fig. 3A and B) were obtained, respectively and they do match with our previous report [10]. Furthermore, in the absence of both M13 and SSG (Fig. C) and in the absence of SSG (Fig. 3D); sphere-like particles are observed and they are well separated too. When there is M13 at the bio-template, still the network-like structures are formed (Fig. 3E). Comparison of the controlled experiments reveals that, both M13 and SSG’ contributions at the bio-template are essential to lead such highly porous and network-like structures. Furthermore, Fig. 3F represents several fold smaller particles as its constituents. Fig. 3G-I demonstrate the SEM-EDX analysis of the ITO/M13-(10)/SSG/AuPt electrode.

To analyze the crystal planes and elements composition, X-ray diffraction (XRD) and X-ray photoelec-

![Fig. 3. SEM images of (A) ITO/M13-(10)/SSG/Au, (B) ITO/M13-(10)/SSG/Pt, (C) ITO/AuPt, (D) ITO/M13-(10)/AuPt, (E) ITO/SSG/AuPt and (F) ITO/M13-(10)/SSG/AuPt electrodes. SEM-EDX analysis of (F).](image-url)
tron spectroscopy (XPS) studies were carried out and the obtained results are summarized in Fig. 4. As can be seen from the Fig. 4A, XRD patterns of the mono- and bi-metallic ITO/M13-(10)/SSG/Au, ITO/M13-(10)/SSG/Pt and ITO/M13-(10)/SSG/AuPt electrodes were compared. XRD peaks marked with the asterisk symbol at 30.5°, 35.3°, 50.9°, and 60.4° (JCPDS card number 39-1058) can be assigned to the bare ITO surface [28] and are neglected in the analysis. Peaks observed at 38.1°, 44.2°, 64.5°, and 77.5°, in Fig. 4A(a) are attributed to the presence of Au with an fcc structure and are corresponds to the crystal planes of (1 1 1), (2 0 0), (2 2 0), and (3 1 1), respectively (JCPDS card number 65-2870). For Pt (Fig. 4A(a)), peaks were witnessed at 39.9°, 46.4°, and 67.8° (JCPDS card number 04-0802), and are corresponds to (1 1 1), (2 0 0), and (2 2 0) crystal planes, respectively, and belongs to fcc crystal structure. The XRD pattern of the ITO/M13-(10)/SSG/AuPt electrode showed peaks at 38.6°, 45.2°, 65.8°, and 78.9°, and are corresponds to (1 1 1), (2 0 0), (2 2 0), and (3 1 1) crystal planes of the AuPt NSs. Due to the atomic level mixing and interdiffusion of Pt atoms to the Au unit cells; slight shifts in comparison with mono-metallic Au and Pt NSs are noticed and are characteristic of the AuPt alloy NSs. Fig. 4B and C represents the XPS analysis of the ITO/M13-(10)/SSG/AuPt electrode. From the survey spectrum (Fig. 4B), existence of elemental Au, Pt, Si, N, and O are confirmed. In addition, core-level spectra of AuPt region was obtained and de-convoluted as shown in Fig. 4C; doublet peaks for Pt0 at 70.9 eV (Pt 4f7/2) and 74.2 eV (Pt 4f5/2), and Au0 at 84.3 eV (Au 4f7/2) and 87.7 eV (Au 4f5/2), are noticed and confirms that both Au and Pt are in their zero oxidation states and are atomically mixed with each other with no phase separation.

3.2. Electro-catalytic activity

To explore the electro-catalytic activity of the fabricated electrodes, Methanol oxidation reaction (MOR) [29-31] in alkaline medium was used as a

![Fig. 4. (A) XRD patterns of (a) ITO/M13-(10)/SSG/Au electrode, (b) ITO/M13-(10)/SSG/Pt electrode and ITO/M13-(10)/SSG/AuPt electrodes. XPS analysis of ITO/M13-(10)/SSG/AuPt electrode: (B) Survey spectrum and enlarged spectra for (C) Au–Pt 4f regions of the modified electrode.](image)

| Modified electrodes | specific mass (mgPt/cm²) | ECSA (cm²) | ECSA (m²/gPt) | onset potential (V) | anodic peak potential (V) | mass activity (mA/mgPt) |
|---------------------|-------------------------|-----------|---------------|---------------------|---------------------------|------------------------|
| ITO/M13-(5)/(Au₅₋₃-Pt₃) | 0.0041 | 0.33 | 8.04 | -0.423 | -0.089 | 21.00 |
| ITO/M13-(10)/(Au₅₋₃-Pt₃) | 0.013 | 0.51 | 3.92 | -0.490 | -0.081 | 11.10 |
| ITO/M13-(5)+SSG/(Au₅₋₃-Pb₃) | 0.0949 | 0.41 | 0.432 | -0.467 | 0.151 | 8.50 |
| ITO/M13-(10)+SSG/(Au₅₋₃-Pb₃) | 0.0022 | 0.27 | 12.27 | -0.482 | -0.057 | 106.90 |
| ITO/M13-(5)/SSG/(Au₅₋₃-Pb₃) | 0.0055 | 0.35 | 6.36 | -0.507 | 0.138 | 112.10 |
| ITO/M13-(10)/SSG/(Au₅₋₃-Pb₃) | 0.00086 | 0.29 | 33.72 | -0.608 | 0.003 | 534.00 |
| ITO/SSG/(Au₅₋₃-Pb₃) | 0.0078 | 0.243 | 3.119 | -0.487 | -0.045 | 31.90 |
| ITO/(Au₅₋₃-Pb₃) | 0.0036 | 0.415 | 11.54 | -0.481 | 0.045 | 129.00 |
| ITO/M13-(10)/SSG/Au | 0.0070 | - | - | - | - | - |
| ITO/M13-(10)/SSG/Pt | 0.0057 | 0.31 | 5.52 | -0.493 | -0.195 | 11.00 |
model system and obtained results are summarized in Figs. 5-8 and Table 1. The rational design of the bimetallic AuPt alloy NSs are always preferred to lower the consumption of the precious Pt metal, in addition combination with the suitable bio-template would help in nucleating the AuPt NSs in an unique way thereby the resulting catalyst will be rich in catalytic activity.[10] To assess the ECSA of the fabricated electrodes, CVs were carried out in the H$_2$SO$_4$ medium; by integrating the area of the hydrogen adsorption behaviour of Pt, ECSA values were in terms of ECSA (m$^2$/g$_{Pt}$) and specific mass (m$g_{Pt}$/cm$^3$) and are given in Table 1. From the Fig. 5A, fabricated electrodes exhibit the characteristic hydrogen adsorption (forward scan) and desorption (reverse scan) peaks between –0.2 and 0 V. The electro-catalytic activities of the ITO/M13-(10)/SSG/Au, ITO/M13-(10)/SSG/Pt, ITO/M13-(10)/AuPt, ITO/SSG/AuP and ITO/M13-(10)/SSG/AuPt electrodes toward MOR were evaluated by recording CVs (Fig. 5B) and amperometric i–t curves (Fig. 5C) in 0.1 M CH$_3$OH + 0.1 M KOH and are given in Fig. 5B and C. Results from the both studies reveals that, in terms of mass activity, ITO/M13-(10)/SSG/AuPt electrode exhibits (Fig. 5B(e) and 5C(e)) enhanced electro-catalytic activity in comparison with the remaining catalysts. Various electrochemical parameters were derived from the Fig. 5A and B and are summarized the Table 1.

In addition, Fig. 5D represents the comparison of ITO/M13-(10)/SSG/AuPt electrode in the (a) absence and (b) presence of 0.1 M CH$_3$OH in the electrolyte; in the absence of CH$_3$OH, catalytic current was not observed which demonstrates the catalytic activity of the ITO/M13-(10)/SSG/AuPt electrode. Further controlled experiments were carried out to reveal the role of bio-template’s components and M13 pulling time as summarized in Fig. 6. As can be seen from Fig. 6A, in the absence of SSG; lower catalytic activities are observed for both 5 and 10 h of pulling time since there is no solid support (SSG). At the ITO/M13/SSG bio-template, little improvement is noticed then the previous one, when compared to 5 h pulling time M13+SSG mixture pulled for 10 h exhibits higher catalytic activity. On contrary, ITO/M13/SSG bio-template demonstrates the several fold

Fig. 5. (A, B, C) CVs of (a) ITO/M13-(10)/SSG/Au, (b) ITO/M13-(10)/SSG/Pt, (c) ITO/M13-(10)/AuPt, (d) ITO/SSG/AuPt and (e) ITO/M13-(10)/SSG/AuPt electrodes in (A) 0.5 M H$_2$SO$_4$ and in (B) 0.1 M CH$_3$OH + 0.1 M KOH at a scan rate of 50 mV/s. (C) Amperometric i–t curves observed for A(a–e) in 0.1 M CH$_3$OH + 0.1 M KOH at an applied potential of –0.3 V. (D) comparison of ITO/M13-(10)/SSG/AuPt electrode in the (a) absence and (b) presence of 0.1 M CH$_3$OH in 0.1 M KOH at a scan rate of 50 mV/s.
higher catalytic activity then the rest. Furthermore, 10 h pulled electrode demonstrates much better performance than the 5 h; it can be attributed that during the elongated pulling time, M13 were assembled well in an ordered manner by compensating their charge. Kinetics studies (Fig. 7) were carried out using ITO/M13-(10)/SSG/Pt and ITO/M13-(10)/SSG/AuPt electrodes and the studies revealing that peak potentials are linearly shifted to more positive region while scale-up the scan rate, which is indicative of irreversible process of MOR. Relationships of anodic peak current (jp) and peak potential (Ep) as a function of different scan rates (ν) were plotted using the parameters derived from the CVs; forward scans. Both Pt and AuPt catalysts exhibits linear relationship (Fig. 7C) between log j and log ν and the slope approximated at 0.209 and 0.208, respectively and which are characteristic of the diffusion controlled process. Besides, irreversible charge transfer process at the both Pt and AuPt catalysts are verified from the linear relationship (Fig. 7D) between Ep and log (ν). To determine the stability of the ITO/M13-(10)/SSG/
AuPt electrode, 100 continuous CVs were recorded for MOR (Fig. 8A) and it is noticed that after 100 continuous cycles around 40.6% decrement in the peak current was observed and it indicates that the present catalyst showed moderate stability towards MOR.

Efficient nucleating ability of the ITO/M13/SSG bio-template and improved catalytic activity of the ITO/M13-(10)/SSG/AuPt electrode can be justified by analysing various aspects based on the observed results. (i) From the structural viewpoint, in comparison with the other bio-templates, granular-like, highly porous and networked AuPt NSs are obtained (Fig. 2I) and such structural features were responsible for the higher ECSA. (ii) Comparison of ITO/M13+SSG and ITO/M13/SSG bio-templates; pulling M13 from the M13+SSG mixture seems not an efficient way to assemble the M13 onto the ITO surface, presence of SSG might neutralize its charge and disturb its capillary action hence, number of M13 molecules and the ordered assembly might be quenched. On the other hand, subsequent introduction of the M13 and SSG onto the ITO surface lead to the distinctive assembly of M13 and the wrapped SSG layer efficiently protects the M13 as well as acts as an ideal solid-support for the electrodeposition of AuPt alloy. In addition the porosity of the SSG layer improves the mass diffusion as well as facilitates the OHads-rich environment during the MOR. (iii) Synergistic catalytic effect of the AuPt; electronic effects associated with Au and Pt accompanied with the bio-template, altogether results in an enhanced oxidation of CH$_3$OH. Above mentioned factors supports that the proposed ITO/M13/SSG bio-template and ITO/M13-(10)/SSG/AuPt catalyst are having beneficial structural features that would convey improved catalytic oxidation of CH$_3$OH. Hence, pulling M13 nanofibers onto an electrode surface was evidently promoting to nucleation, growth, and catalytic activity. Such fabrication approach is suitable candidate for constructing the efficient bio-template to nucleate and mineralise the variety of inorganic nanoscale materials.

4. Conclusions

Pulling M13 nanofibers onto the electrode surface to construct a bio-template, and then applying it for the nucleation and growth of AuPt NSs have greatly enhanced the surface structure of as-synthesized AuPt catalyst. The synergistic ability ITO/M13/SSG bio-template was revealed from the analysis of various controlled experiments. The wrapped SSG layer at the bio-template had better served as suitable solid-support for the nucleation and growth as well as facilitating OHads-rich environment for the CH$_3$OH oxidation. The pulling time of the M13 nanofibers onto the electrode surface had greatly affect the catalytic activity. The advantages we claim for these facile bio-templated AuPt alloy fuel cell catalysts are: (i) Human friendly M13 nanofibers can be easily prepared in a laboratory simply by infecting the bacteria (E. coli) there by the production cost of the biomolecules can be lowered. (ii) For the first-time M13-pulled electrode surface was used as a substrate for the electrodeposition of the noble metal NSs. (iii) Major coat proteins of the M13 nanofibers in association with the SSG had shown specific affinity
towards the Au and Pt metal precursors. This facile methodology might be extended to other metals and metal oxides, and the designed bio-template should offer capable scaffolds for energy harvesting and storage applications.

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