Hierarchical Bimetallic AgPt Nanoferns as High-Performance Catalysts for Selective Acetone Hydrogenation to Isopropanol

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ABSTRACT: A combinative effect of two or more individual material properties, such as lattice parameters and chemical properties, has been well-known to generate novel nanomaterials with special crystal growth behavior and physico-chemical performance. This paper reports unusually high catalytic performance of AgPt nanoferns in the hydrogenation reaction of acetone conversion to isopropanol, which is several orders higher compared to the performance shown by pristine Pt nanocatalysts or other metals and metal–metal oxide hybrid catalyst systems. It has been demonstrated that the combinative effect during the bimetallisation of Ag and Pt produced nanostructures with a highly anisotropic morphology, i.e., hierarchical nanofern structures, which provide high-density active sites on the catalyst surface for an efficient catalytic reaction. The extent of the effect of structural growth on the catalytic performance of hierarchical AgPt nanoferns is discussed.

1. INTRODUCTION

It has been well-known that the introduction of a foreigner element, for example, during doping or alloying, to a particular nanocrystalline system can modify the intrinsic physico-chemical properties of the nanocrystalline system.1,2 In many cases, the material’s new physico-chemical properties are much superior compared to their individual intrinsic properties.3 This resulted from a combinative effect of individual material’s properties that can compensate their intrinsic weakness, yielding novel physico-chemical properties.4–6 Such a combinative effect is not only on the physico-chemical properties of the materials but also extends to their crystal growth behavior.7–9 This will promote the formation of novel nanocrystals’ structures and morphologies. Unusual electrical, optical, and catalytic properties are expected to be obtained from this process.

The Pt nanocatalyst is well-known for its highly reactive performance in Pt. Unfortunately, owing to, in most cases, the coordination between Pt atoms and reactants as well as products involving a strong binding nature, site poisoning on the Pt nanocatalyst is unavoidable and becomes a critical issue in the catalytic reaction. Bimetallization of Pt with other metals may successfully eliminate such a major drawback in its catalytic properties due to the combinative effect of the individual physico-chemical properties of the metallic components,1–5,9,21–24 producing high-performance nanocatalyst systems. For example, bimetallization of Pt with Au,6 Pd,25 Ru,26 Rh,27 or Ni28 has exhibited excellent performance in accelerating the direct methanol fuel cell reaction and some reaction of organic contaminant degradation, and in general case, its performance is several orders higher compared to individual Pt catalytic performance. In a different attempt, it has also been reported that bimetallization of Pt with Fe could effectively expand its catalytic properties in the CO oxidation reaction.29

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We have carried out a study on the role of a synthetic reagent in the growth of metals $^{30-32}$ and metal oxide $^{33,34}$ nanostructures and nanostructures with a controlled-morphology $^{35,36}$ and atomic composition $^{37}$ for solar cells, $^{38,39}$ light-emitting diodes, $^{40}$ catalysis, $^{41-43}$ non-linear optics, $^{44-47}$ and sensors, $^{48-52}$ which were successfully obtained. We have also discovered that the morphology, surface structure, and atomic stoichiometry in the nanocrystals strongly influence their electrical, optical, electronic transport performance, and catalytic properties, exhibiting high-performance in applica-

Figure 1. Representative FESEM images of AgPt NFn recorded with low (A) and high magnification (B), and its typical XRD spectrum profile (C). (D) EPMA element mapping of the sample; (a) is its SEM image, (b) is mapping for the Ag element and (c) for the Pt element. (E) Plot of the atom concentration of Ag in the AgPt nanofern versus its precursor concentration.
2. RESULTS AND DISCUSSION

2.1. Characterization of AgPt NFn. Figure 1A,B show the typical field emission scanning electron microscopy (FESEM) image of AgPt NFn that has been successfully grown on the indium tin oxide (ITO) substrate surface. The structure of AgPt NFn is constructed by dozens of branches consisting of nanopyramids with stems. As Figure 1 reveals, the structure of AgPt NFn seems to be highly reactive, as it contains a large density of high-energy sites of spiky structures for the active surface reaction and charge transfer. The phase crystallinity of the AgPt NFn is verified by X-ray diffraction (XRD) analysis (see Figure 1C). As shown in Figure 1C, no phase segregation is observed but instead the diffraction peaks are related to face-centered cubic (fcc) Pt (JCPDS 70-2057) with some distortion. In addition, no diffraction peaks related to fcc Ag appeared in the spectra. Electron probe microanalysis (EPMA) elemental analysis result shown in Figure 1D,E nevertheless reveals the nature of Ag and Pt elements distribution in the AgPt NFn. It can be understood that the Ag ions are very well dissolved in the AgPt NFn structure and its atomic content in the AgPt nanoferns can also be easily modified in the reaction by changing the Ag ion precursors’ concentration in the growth reaction (Figure 1E). These results confirm the successful bimetallization process of Ag and Pt. With special morphology of a spiky structure, the AgPt NFn should demonstrate excellent catalytic properties.

AgPt NFn formation can be described by the following equation

\[
K\text{PtCl}_6^{2-} + H_2O(1) \rightarrow 2K^{+} + \text{PtCl}_6^{2-} \quad (\text{ion dissociation})
\]

During a liquid phase deposition synthesis method, K\text{PtCl}_6, precursor for Pt, dissociates into positive ions of 2K\text{+} and negative ions PtCl\text{6}^{2-}. The formic acid will then reduce PtCl\text{6}^{2-} ions to produce PtCl\text{4}^{2-} ions and then to Pt atoms (Pt\text{0}), which then nucleates forming nanocrystallites. At the same time, the AgNO\text{3} as the Ag precursor also followed the Pt reduction and nucleation process. In the synthesis process, the sodium dodecyl sulfate (SDS) surfactant may form complexes with metal ions before undergoing the reduction process. Complex formation between metal ions and SDS will accelerate the metal ion reduction process and at the same time will control the growth morphology of the nanostructures.

The lattice mismatch between Ag and Pt (i.e., as high as 0.67\%) leads to an anisotropic crystal growth of AgPt NFn as a result of distortion of structural growth orientation of the Pt fcc system. However, the increase in the Ag content in the NFn does not modify the phase crystallinity of the sample as verified by XRD analysis (see Figure 2A). Nevertheless, the strain in the lattice increases with the increase in the Ag content in the NFn, as shown in Figure 2B; the main Bragg plane angle shifted. The increase in the lattice strain may modify the electron cloud distribution in the NFn, producing unique properties.

Figure 2. (A) XRD spectra for AgPt NFn grown using different Ag precursor concentrations, namely 0.067 (a), 0.13 mM (b), 0.20 mM (c), and 0.33 mM (d). (B) The zooming in analysis of the (111) Bragg peak showing significant lattice distortion upon Ag atom concentration change in the AgPt nanoferns.
surface chemistry properties for active catalytic properties and charge transfer process.

2.2. Catalytic Performance of AgPt NFn. Figure 3 shows the typical optical absorption spectrum of acetone during the hydrogenation process under microwave irradiation (power of 110 W) in the presence of AgPt NFn sample, i.e., prepared by an Ag precursor of 0.20 mM.

As can be seen in Figure 3 the absorbance of acetone has drastically decreased with the increase in its concentration during the hydrogenation reaction (see Figure 3C for the concentration calibration curve). This fact is an indication of successful hydrogenation of acetone presumably to isopropanol. Acetone absorbance drastically decreased with the increase in the reaction time and nearly zero value when the reaction time reached 20 s. To understand the product of acetone conversion during the hydrogenation reaction, we carried out a high-performance liquid chromatography (HPLC) analysis. The result is shown in Figure 4. As can be seen in Figure 4C, two separate peaks were found in the spectrum at retention times of 25.501 and 27.389 s. These two peaks correspond to the retention times of acetone and isopropanol, respectively (see HPLC spectra for acetone and isopropanol in Figure 4A,B).

Thus, these results confirmed the successful hydrogenation of acetone to produce isopropanol. From the figure, it can also be understood that no peaks related to the retention time of other compounds are observed, inferring that the AgPt NFn are highly selective to convert acetone during the hydrogenation reaction to isopropanol.

By using the concentration calibration curve for acetone shown in Figure 3C, it is known that at the first 10 s of the reaction the percentage of isopropanol formation has reached the value of 47% and it increased to 95.5% when the reaction time was extended to 20 s. The kinetic rate value for this reaction was as high as $1.2 \times 10^{-1}$ s$^{-1}$. This value is much higher compared to the recently reported results on the catalytic hydrogenation of acetone to isopropanol (see Table 1). By considering the catalyst mass of AgPt NFn nanoparticles on one slide of ITO, which is approximately 34 μg, the turn over number (TON) and the turn over frequency (TOF) of the reaction were calculated. The TON and TOF were as high as $3.8 \times 10^3$ and $3.8 \times 10^2$ s$^{-1}$, respectively, deduced from the half-way value of the reaction’s TON.

We then evaluated the effect of the Ag precursor concentration on the catalytic performance of AgPt NFn by using four different concentrations within the range of 0.067–0.33 mM. The typical kinetic rates of the reaction of the samples are presented in Figure 5. As can be seen in Figure 5, the kinetic rate increased with the increase in the Ag concentration and optimum in the sample utilizing the Ag concentration of 0.2 mM. However, the performance dropped when the Ag concentration was higher than 0.2 mM. The catalytic reaction is determined by the amount of catalyst used. To eliminate the effect of the catalyst content in the catalytic reaction and to obtain the real role of the Ag concentration in the AgPt NFn, we normalized the catalytic performance over the catalyst mass. The result for the kinetic rate of the reaction
of the AgPt NFn with different Ag contents is shown in Figure 5B. As Figure 5B reveals, the catalyst performance exponentially increased with the Ag concentration in the AgPt NFn and is likely to saturate at a concentration of approximately 0.28 mM, which is in good agreement with the results discussed earlier.

The increase of the kinetic rate value upon the increase of the Ag content in the AgPt NFn could be related to the enhancement of hydrogen adsorption onto the surface of AgPt NFn. Cyclic voltammetry analysis as presented in Figure 6 indicated that there has been an increase in the faradaic current at the potential window of −0.8 to −0.5 V, i.e., potential for hydrogen reduction and oxidation. When the Ag content in the NFn increases, the maximum current was detected on the sample using an Ag precursor concentration of 0.2 mM. The current decreased when the Ag content was further augmented. The increase in the hydrogen adsorption onto the surface of AgPt NFn probably enhances the hydrogenation of acetone that are also attached on the AgPt NFn surface. Oxidation and reduction of different redox species were also observed in the analysis results. For example, the oxidative dissolution of Ag to form Ag2O (at ca. 0.41 V), reduction of Ag2O to metallic Ag (at ca. 0.43 V), reduction of the oxidized Pt (at ca. −0.30 and −0.10 V), and anodic oxidation of Pt (at ca. −0.30 and 0.0 V). It is noted that the AgPt NFn morphology was more or less similar even though the concentration of Ag was varied in the AgPt NFn as judged in the FESEM morphological (Figure 7) and XRD analysis (Figure 2). Therefore, the enhancement of catalytic performance of the AgPt NFn could be solely attributed to the role of the Ag ion in the lattice in modifying the surface chemical state of the sample. Furthermore, an increase of the Ag concentration in the bimetallic system likely led to an enhancement in the surface pressure, in which in more extreme cases, it might reduce the density and the coherence of the nanocrystal structure, thereby affecting the active site of the catalyst.61 This assumption likely agrees well with the X-ray photoelectron spectroscopy (XPS) analysis results (Figure 8) for the sample with different Ag ion concentrations where the metallic state of both Ag and Pt (curve 1 in Figure 8B,C), the key state for the active surface reaction, increased with the increase in the Ag ion concentrations in the samples (see Table 2). However, excessive Ag in the reaction may drive the formation of excessive oxides, deteriorating the catalytic performance. XPS analysis further reveals that there has been a shift in the binding energy of both Pt and Ag elements (positive and negative, respectively) than their bulk metal states (Figure 8B,C). This indicates that the Ag exhibits a greater tendency to

### Table 1. Comparison of the Efficiency of the AgPt NFn Nanocatalyst for Acetone Hydrogenation with the Reported Results

| catalyst          | cat. mass | react. time | degrad. (%) | $k_{cat}$ | conversion efficiency | refs |
|-------------------|-----------|-------------|-------------|-----------|------------------------|------|
| AgPt NFn          | 34 μg     | 20 s        | 95.5        | $1.2 \times 10^{-3}$ s$^{-1}$ | 0.26% μg$^{-1}$ W$^{-1}$ | current results |
| AuPt NFB          | 35.5 μg   | 40 s        | 96          | $8.1 \times 10^{-3}$ s$^{-1}$ | 0.24% μg$^{-1}$ W$^{-1}$ | 6 |
| Pt NCS            | 33 μg     | 2 min       | 65          | $4.5 \times 10^{-3}$ s$^{-1}$ | 0.17% μg$^{-1}$ W$^{-1}$ | 6 |
| amorphous-Pt nanofiber | 30 μg   | 2 min       | 40          | $2.7 \times 10^{-3}$ s$^{-1}$ | 0.01% μg$^{-1}$ W$^{-1}$ | 56 |
| PtGa$^a$          | 50 mg     | 12 h        | 88          | $1.6 \times 10^{-1}$ h$^{-1}$ | $1.76 \times 10^{-5}$ mg$^{-1}$ C$^{-1}$ | 54 |
| Rh$^b$            | 200 mg    | 13 h        | 98          | $2.1 \times 10^{-1}$ h$^{-1}$ | $4.9 \times 10^{-5}$ mg$^{-1}$ C$^{-1}$ | 54 |
| Raney Ni$^b$      | 2900 mg   | 1.5 h       | 99.8        | $3.6 \times 10^{-2}$ min$^{-1}$ | $4.31 \times 10^{-5}$ mg$^{-1}$ C$^{-1}$ | 57 |
| SiO$_2$Fe$_2$O$_4$$^a$ | 0.1 mg  | 100 s       | 41          | $5.5 \times 10^{-3}$ s$^{-1}$ | 0.003% μg$^{-1}$ W$^{-1}$ | 58 |
| Co/Al$_2$O$_3$$^b$ | 0.5 mg   | 15 h        | 64          | $5.4 \times 10^{-2}$ h$^{-1}$ | $6.4 \times 10^{-5}$ μg$^{-1}$ C$^{-1}$ | 59 |
| NiO, CoO$^b$      | 0.5 mg    | 15 h        | 50          | $4.2 \times 10^{-2}$ h$^{-1}$ | $5 \times 10^{-7}$ μg$^{-1}$ C$^{-1}$ | 59 |
| Raney Co$^b$      | 7.8 mg    | 30 h        | 82.5        | $3.3 \times 10^{-2}$ h$^{-1}$ | $8.81 \times 10^{-5}$ μg$^{-1}$ C$^{-1}$ | 60 |

$^a$Microwave (110 W) was applied. $^b$Temperature of higher than 100 °C and H$_2$ was used.

**Figure 5.** (A) Time variation of concentration of acetone over the AgPt NFn prepared using different Ag precursor concentrations. (B) The kinetic rate per mass of the AgPt NFn prepared at different Ag precursor concentrations normalized over their mass.

**Figure 6.** Cyclic voltammograms of AgPt for different concentrations of Ag precursors, namely (a) 0.067 mM, (b) 0.13 mM, (c) 0.20 mM, and (d) 0.33 mM. The scan rate and temperature are 50 mV s$^{-1}$ and 25 °C, respectively.
lose electrons than Pt (i.e., electron transfer from Ag to Pt), perturbing the electronic systems of Pt. However, such a bimetallization process also promotes the facile electron transfer across the Fermi level of the two materials’ interface, enhancing the surface activity of the nanofern structure. Nevertheless, the existence of different species other than the pure metallic state is also considered as an additional factor for the enhancement of the catalytic performance. It has also been widely reported that the presence of the synergic effect of metallic states, metal cations, and metal oxide states actually enhances the catalytic performance via unique properties of metal–metal or metal–cation direct bonding electronic system (d electron) that accelerates charge transfer in the catalytic process. In many cases, this phenomenon improves the catalytic activity and selectivity behavior due to the formation of active hydrogen species, such as H− and H+. The improvement in the stability of the catalyst surface is also observed due to the presence of oxide species on the catalyst surface. Unique to the existence of the bimetal system, the variation of the metal ion distribution on the surface of the AgPt may produce excess heat that may accelerate the hydrogenation reaction process.

We also evaluated the catalytic stability of AgPt NFN by reusing the sample in fresh acetone hydrogenation reactions. Figure 9 shows the reaction kinetic rate of catalytic hydrogenation of acetone over a recycle AgPt NFN sample. As can be seen in the figure, there is no significant change in the kinetic rate of the reaction even though the AgPt NFN has been used three times in the fresh acetone hydrogenation reaction. For example, the kinetic rate of the reaction was as high as 1.2 × 10−1 for the first cycle of the reaction. It changed to 1.1 × 10−1 and 1.0 × 10−1 when used for the second and third time, respectively. With the reduction of efficiency as low as ±8% per repetition, it indicates that the AgPt NFN catalyst is very stable and has a limited poisoning process.

In catalytic hydrogenation of acetone under microwave irradiation, water molecules may split producing e−, H+, OH−, H2O2, H, and O· species that in turn play a key role in the hydrogenation process. The electrons that are formed from this process will adsorb or bind to Ag or Pt sites of AgPt NFN and then drives the formation of hydrogen via interaction with adsorbed or the adjacent H+ to the catalyst surface. It is expected that the bimetallic system of the AgPt NFN may have superior catalytic activity over the monometal system due to the following assumptions: (i) the existence of a ligand and the ensemble effect. It is normal in the bimetallic system, depending on the nature of atomic distribution in the lattice, the identical atoms tend to assemble with each other during the growth process producing unique chemical properties on the surface. This is called as the ensemble effect. Interensemble interaction may further enhance the physico-chemical properties of the surface for high-performance catalytic process. It is also understood that the addition of the Ag atom in the Pt lattice may modify the electron distribution of the Pt 5d orbital, especially the atoms near the Pt atoms, generating a ligand effect, in which in many processes it generates heat energy accelerating the hydrogenation process. In addition, hydrogen from the bulk reaction may easily adsorb onto the Ag site of the surface, enabling the rapid hydrogenation process of acetone. (ii) Modification of the surface atom distribution. The co-existence of Ag atoms along with Pt may compensate the disadvantageous properties.
of each metal. For example, Pt is well-known for its active and strong binding to hydrogen that in many cases it causes rapid poisoning of the catalyst surface. This brings about the surface to be quickly deactivated within a short time of reaction. By the presence of Ag, the highly active surface chemistry of Pt is assumed to be reduced so that the bonding nature of the adsorbate becomes more dynamic.\textsuperscript{72−74} The catalytic site poisoning is expected to be decreased. As the Ag also demonstrates catalytic activities to some extent, combination with the Pt catalytic properties may also improve the selectivity nature of the catalytic process.\textsuperscript{75} Thus, the product of the hydrogenation of acetone is solely isopropanol. (iii) Improvement of analyte adsorption. It is well-known that the analyte adsorption onto the catalyst surface is strongly site dependent. The bimetallization process modifies the density of state of the d-orbital of Pt as a result of d-band mixing. Because the Ag’s d-band (4d) is lower than Pt (5d), the mixing process has improved the exothermicity of the Ag site so that the analyte adsorption will also favor to attach onto the Ag site.\textsuperscript{76} Thus, the combination of highly active sites of Pt and Ag will improve the analyte adsorption on the AgPt NFn surface. Such electronic nature of the AgPt NFn surface in turn easily

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**Figure 8.** XPS spectra for AgPt NFn with Ag precursor’s concentration of 0.2 mM. Pt concentration is 1 mM. (A) Wide range scan spectrum. (B, C) High-resolution scan for Ag 3d and Pt 4f, respectively. (D, E) The high-resolution spectrum for Ag 3d and Pt 4f at different Ag concentrations, namely 0.07 mM (a), 0.13 mM (b), 0.20 mM (c), and 0.33 mM (d).

**Table 2. Surface Energy and Relative Intensity of AgPt NFn’s Surface Composition with Different Ag/Pt Molar Ratios**

| Ag/Pt molar ratio | Ag/Pt atomic ratio | Ag 4d-\(\frac{7}{2}\) (eV) | Ag(0) (%) | Ag(0) (%) | Ag(0) (%) | Pt 4f-\(\frac{7}{2}\) (eV) | Pt(0) (%) | Pt(0) (%) | Pt-O (%) | O-Pt-O (%) |
|-------------------|-------------------|----------------|--------|--------|--------|----------------|--------|--------|--------|---------|
| 0.07:1            | 1:30.6            | 367.70         | 70.81  | 29.19  | 71.77  | 45.02         | 32.14  | 22.84  |        |         |
| 0.13:1            | 1:24.9            | 367.85         | 72.65  | 27.35  | 71.90  | 49.09         | 30.21  | 20.72  |        |         |
| 0.20:1            | 1:18.6            | 368.10         | 89.97  | 10.03  | 72.03  | 54.08         | 29.00  | 16.92  |        |         |
| 0.30:1            | 1:12.5            | 368.20         | 93.99  | 8.01   | 72.40  | 59.47         | 25.33  | 15.20  |        |         |

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**Figure 9.** Plots of \(\ln(C_o/C_i)\) vs reaction time for acetone hydrogenation over the multiple-used single slide AgPt NFn. Inset shows the percentage of isopropanol produced over three times catalytic repetition processes under microwave radiation exposure.
donates an electron to adsorbed hydrogen and acetone, weakening them for effective and rapid catalytic hydrogenation of acetone. (iv) The high-energy active site possessing hierarchical structure composed of spiky isosceles tetrahedral nanopyramid nanofern. The introduction of the Ag ion into the Pt lattice may have caused distortion in the nanocrystal lattice growth orientation and projected a highly anisotropic nanofern structure, which is a hierarchical structure that is composed of a spiky isosceles tetrahedral nanoparticle with a high-energy (001) basal plane. This characteristic should be promising for catalytic reactions. On the basis of these properties, the AgPt NFn generates exceptionally high catalytic performance, which is potential for a wide range of catalytic reactions and surface chemistry applications.

In our previous study, we have examined the effect of precursor concentration on the structural growth of the AgPt nanostructure. We found that the surfactant and other precursor concentrations influence the structural growth and the surface chemistry properties of the nanocatalysts. Nevertheless, in this study, as the catalytic performance is related more to the structure, where the highly anisotropic structure that contains large-scale of high-energy site, such as sharp-tipped spike, is the most active structure as well as the removal of the surfactant residue on the surface of the catalyst by plasma pre-treatment prior to catalysis application, the effect of the surfactant on the catalytic performance in this paper was not evaluated.

Nevertheless, while the catalytic activity of the AgPt nanofern in the hydrogenation of acetone has been obtained, the selectivity properties, particularly related to the concentration of Ag and Pt in the nanofern, has not yet been evaluated. It is true that the Ag and Pt concentrations will affect the selectivity properties of the nanocatalysts. However, because of a strong effect of Ag and Pt concentrations on the structural growth, where the change in concentrations will change the structural symmetry, we cannot obtain the effect of Ag and Pt concentrations on the catalytic selectivity performance. However, the study of the effect of Ag and Pt concentrations on the catalytic selectivity properties of the AgPt nanofern is underway and will be reported in different paper.

3. CONCLUSIONS

The catalytic properties of a bimetallic AgPt nanofern in the hydrogenation of acetone into isopropanol were investigated. The bimetallic nanostructure demonstrated excellent catalytic properties showing a remarkably high reaction kinetic rate, approximately $1.2 \times 10^{-1}$ s$^{-1}$ in a typical process, during the conversion of acetone into isopropanol, which was equivalent to TON of $3.8 \times 10^7$ and $3.8 \times 10^5$ s$^{-1}$, respectively. This catalytic performance is very high in terms of heterogeneous catalytic reactions. It is also observed that the AgPt nanofern shows an outstanding selectivity properties that only allows the acetone to be converted into isopropanol and not into other products. In addition, the AgPt nanofern exhibits limited site poisoning, enabling the catalyst system to be used repeatedly in a subsequent fresh reaction with a relatively low performance drop. The existence of the ligand and ensemble effect, which is due to the fluctuation in the atomic distribution of element in the bimetal, unique surface atom distribution, and availability of wide area high-energy site are believed to be the key factors for the excellent catalytic performance. The catalytic properties of the AgPt nanofern can be potentially utilized in a wide range of fields including sensors, photocathodes in dye sensitized solar cells, and electronic applications.

4. EXPERIMENTAL SECTION

The AgPt nanofern on an indium tin oxide (ITO) substrate was prepared by following our earlier reported technique. Briefly, in the typical process, a clean ITO substrate was immersed into an aqueous solution that contains 1 mM K$_2$PtCl$_6$ (Fluka), 0.2 mM silver(I) nitrate (Fluka), 10 mM formic acid (Fluka), and 10 mM sodium dodecyl sulfate (SDS) (99.9%, Fluka). The volume of the reaction was 15 mL. During the reaction, the solution was continuously stirred approximately at 500 rpm. The reaction was proceeded for 30 min at a temperature of 40 °C, resulting in the formation of the AgPt nanofern. The sample was then taken out from the solution and washed with a plenty of deionized water, followed by being dried using a nitrogen gas flow. AgPt nanoferns (NFn) with different Ag contents were prepared by varying the Ag precursors, i.e., AgNO$_3$, in the reaction, namely from 0.067 to 0.33 mM. The Pt precursor concentration as well as other reagents were fixed.

Field emission scanning electron microscopy (FESEM) using a Zeiss Supra 55VP FESEM apparatus with a 1.0 nm resolution operating at 30 kV with a function of electron probe microanalysis (EPMA) was performed to evaluate the AgPt NFn morphology. Meanwhile, X-ray diffraction (XRD) spectroscopy utilizing a Bruker D8 XRD spectrometer with a Cu K$_\alpha$ irradiation and a scanning rate of 0.025° s$^{-1}$ was carried out to analyze the crystal structure of AgPt NFn. The chemical state of the AgPt NFn was characterized using an X-ray photoelectron spectroscopy (XPS) technique using a Kratos XSAM-HS XPS apparatus. The XPS data were analyzed via curve-fitting utilizing Shirley-type background subtraction of Gaussian–Lorentzian mixed function (70 and 30% for the Gaussian and Lorentzian components, respectively, as the line shaping). The spectra were referenced to C 1s of a binding energy of 284.8 eV. During the XPS measurement, the samples were treated with Ar plasma for 10 min to remove any contaminants or organic waste on the catalyst's surface. After that, the samples were stored in special polystyrene dishes that are mainly used for a tissue culture process, which is proved to be very effective for preventing the ingress of contaminant, prior to XPS measurement. Nevertheless, it is normal during the transfer of the sample for XPS measurement that the sample is exposed to the ambient. However, this will not affect the surface properties of the samples. Thus, the XPS result will be representative.

The catalytic properties of the AgPt NFn were examined in the acetone hydrogenation process under microwave irradiation. During the reaction, 10.0 mL of 0.1 M aqueous acetone solution that was prepared in a glass vial was placed in a Teflon tube for microwave irradiation in a home appliance microwave system with a controlled microwave power. A microwave power of 110 W was adopted during the reaction. The hydrogenation reaction of acetone to produce isopropanol was verified by evaluating the optical absorbance of the solution reaction using a Perkin Elmer Lambda 900 UV–visible spectrophotometer every 10 s interval and by high-performance liquid chromatography (HPLC) Agilent 1200 Series Rapid Resolution HPLC system operated under isocratic elution conditions using a Phenomenex RoA 300 × 7.8 mm$^2$ column. For the HPLC analysis, a mobile phase of 0.005 N...
H₂SO₄ solution with a flow rate of 0.6 mL min⁻¹ and a column temperature of 60 °C was used.

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**Notes**

The authors declare no competing financial interest.

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