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Gold-Loaded Nanoporous Iron Oxide Cubes Derived from Prussian Blue as Carbon Monoxide Oxidation Catalyst at Room Temperature

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**Publication Details**

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Abstract
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Keywords: metal oxides, CO oxidation, metal nanoparticles, metal-organic frameworks, mesoporous materials
Abstract

This work reports the preparation of carbon monoxide (CO) oxidation catalysts based on gold nanoparticles supported on nanoporous iron oxide nanocubes. By heat-treating Prussian blue (PB) nanocubes at various temperatures between 250-450 °C under air atmosphere, nanoporous iron oxide cubes with surface areas of up to 100 m$^2$ g$^{-1}$ are obtained. Owing to the relatively large surface area and nanoporous structure, the as-synthesized iron oxide cubes can be loaded with up to 11 wt% of Au nanoparticles without significant aggregation. When employed as catalysts for CO oxidation, the Au-loaded nanoporous iron oxide cubes exhibit high CO conversion rate of over 95 % at room temperature under 0.1 L·min$^{-1}$ of CO gas flow, with specific activity of up to 1.79 mol$_{\text{CO}}$·g$_{\text{Au}}$·h$^{-1}$. The high catalytic performance of the Au-loaded nanoporous iron oxide cubes for CO oxidation is contributed by various factors, including: (i) the high surface area of the iron oxide cubes which lead to the availability of more sites for the adsorption of oxygen molecules to react with carbon monoxide to generate more carbon dioxide (CO$_2$); (ii) the presence of nanopores which enhances the diffusivity of the reactant molecules during the catalytic reaction and improves dispersion of the deposited gold nanoparticles while also preventing their aggregation at the same time and (iii) the small size of the deposited gold nanoparticles (2-5 nm) which falls within the ideal size of gold nanoparticles for achieving high CO conversion.
Introduction

Vehicle and industrial emissions have greatly contributed to the release of harmful CO gas into the atmosphere because of the incomplete burning of fossil fuels. CO gas presents many health hazards to humans as it readily binds with haemoglobin in the blood to form carboxyhaemoglobin which can lead to serious respiratory diseases, vomiting, nausea, and even death at high concentration. Therefore, it is important to capture or convert CO gas into non-toxic CO$_2$ before it is emitted into the air. CO oxidation is one of the most commonly studied catalytic reactions, owing to its technological importance and fundamental interest. At present, noble metals, such as gold (Au), platinum (Pt), palladium (Pd), and rhodium (Rh) are among the most widely used catalysts for CO oxidation due to their high reactivity and stability. Despite their high catalytic activity, however, the high cost, high operating temperature ($\geq 150 ^\circ$C), scarcity and ease of decontamination of these noble metals have impacted their practical applications. Thus, the deposition of noble metals onto porous support materials has become one of the viable options for increasing their attractiveness for industrial applications. The utilization of porous support materials is expected to not only to reduce the usage of noble metals but also to enhance the overall catalytic activity, as some active supports possess the capability to interact with the noble metals. Although bulk gold (Au) shows poor catalytic activity, it is well known that supported Au nanoparticles (NPs) exhibit high catalytic activity at lower temperatures. This is particularly important as CO oxidation at room temperature is gaining more momentum for important practical applications, such as CO sensors, CO safety gas masks, and CO abatement in air purifiers. As such, many studies have been performed in the past to develop highly efficient catalysts for low temperature CO oxidation catalyst based on supported Au NPs.

The selection of support materials and preparation methods plays a key role in determining the catalytic activity of supported noble metal catalysts. Transition metal oxides, such as Fe$_x$O$_y$, Co$_3$O$_4$, MnO$_x$ and TiO$_2$ exhibit great potential as support materials for noble metal NPs due to their high chemical and thermal stabilities, wide abundance, and low cost. In addition, some oxides can further enhance the overall catalytic activity of the catalysts by enabling CO to react with the adsorbed oxygen species on their surface and the intermediate or oxygen provided by the support themselves.
have gained significant attention as support materials for noble metal NPs owing to their wide abundance, low production cost, good safety, and environmentally friendliness. In fact, Au NPs supported on iron oxide catalysts (Au/Fe$_x$O$_y$) is well known as one of the most active catalysts for CO oxidation. The size, morphology, and porosity of the iron oxide supports can directly influence the catalytic performance of iron oxide-supported noble metal catalysts. Hence, many efforts have been devoted to synthesizing versatile morphologies of iron oxides, including nanospheres$^{[20]}$, nanocubes$^{[21-22]}$, nanorods$^{[23]}$, nanotubes$^{[24]}$, hollow spheres$^{[25]}$, and hierarchical flower-like structure$^{[26]}$. Furthermore, in recent years there has been a growing interest in the utilization of mesoporous oxides in catalytic reactions. In our recent study, Au NPs supported on two-dimensional maghemite (γ-Fe$_2$O$_3$) nanoflakes with high surface area showed very high specific activity for CO oxidation at room temperature owing to the improved dispersion of Au NPs and increased amount of reaction sites for the adsorption of CO molecules$^{[27]}$.

Metal-organic frameworks (MOFs) or porous coordination polymers (PCPs) consisting of covalent linkages between metal ions and organic ligands have been widely used as sacrificial templates for preparing nanoporous materials due to their large surface areas and controllable compositions.$^{[28-29]}$ Among various coordination polymers, Prussian blue (PB) and its analogues, in which the metal components are joined together by cyano-ligands through coordination bonds, have been also considered as attractive precursors for the preparation of nanoporous metal oxides with high surface area and large pore volume.$^{[30]}$ So far, PB-derived nanoporous iron oxides have been used for lithium-ion batteries,$^{[31]}$ supercapacitors,$^{[32-33]}$ drug delivery,$^{[34]}$ and $p$-nitrophenol reduction.$^{[35]}$ However, their utilization as support materials for noble metal NPs for CO oxidation reaction has rarely been explored.

In this work, we have utilized PB cubes as sacrificial template for the preparation of nanoporous iron oxide cubes. The PB cubes were calcined at different temperatures, including 250 °C, 350 °C, and 450 °C and these nanoporous iron oxide cubes were subsequently loaded with Au NPs through the deposition-precipitation (DP) method. Although it has been generally known that a higher loading of Au NPs tends to decrease the catalytic activity due to their aggregation, the as-prepared PB NCs can be loaded with a higher amount of Au NPs of up to 11 wt% without significant aggregation. The Au-loaded nanoporous iron oxide cubes were then
employed as catalysts for CO oxidation at room temperature and the possible reasons behind the good catalytic performance is discussed.

Results and Discussion

Thermogravimetric analysis (TGA) was used to check the thermal decomposition behavior of the PB nanocrystals, as shown in Figure 1. The initial weight loss up to 150 °C is attributed to the removal of physisorbed or chemisorbed water. The second weight loss starting from 150 °C to 250 °C corresponds to the loss of crystalline water and the sharp curve from 250 °C to 350 °C corresponds to the decomposition of the cyanide group of PB. Further critical weight loss is not observed after 350 °C, indicating the complete decomposition of PB. Based on this data, the starting PB cubes were calcined at various temperatures, including 250 °C, 350 °C and 450 °C, in order to convert the PB into iron oxide.

The surface morphology of the PB cubes and the corresponding iron oxide cubes were investigated by SEM. The PB sample exhibits cubic-like structure with an average particle size of 120 nm, as shown in Figure 2a. Following calcination at 250 °C, the cubic-like structure of the original PB NCs is well-preserved, although the surface of the cubes becomes slightly rough (Figure 2b). With the increase of the temperature to 350 °C, these NCs become more porous, as indicated by the increasing roughness of the surface, however their cubic-like structure is still well-maintained (Figure 2c). When the calcination temperature was raised further to 450 °C, although the resulting iron oxide cubes become more porous, some collapsed or broken cubes are also observed (Figure 2d). The porosity of these iron oxide cubes originates from the decomposition of the cyanide ligands of PB and the removal of adsorbed water molecules.

The crystal structure and phase composition of the original PB cubes and the corresponding iron oxide cubes obtained at different calcination temperatures were checked by wide-angle XRD. From Figure 3a, it can be observed that the as-synthesized PB cubes are highly crystalline and the observed diffraction peaks match well with the standard diffraction pattern of fcc PB (JCPDS No. 73-0687). No other peaks belonging to impurities were detected, indicating the high purity of the obtained PB NCs. The XRD patterns of the calcined PB cubes, i.e., PB-250, PB-350, and PB-450 (It is noted that the applied calcination temperatures are included in the sample names,) show the (220), (311), (400), (422), (511), and (440) peaks of \( \gamma \)-Fe\(_2\)O\(_3\) (JCPDS No. 39-
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1346) as well as the (222), (440), and (622) peaks of $\beta$-Fe$_2$O$_3$ (JCPDS No. 39-0238) (Figure 3b). It is difficult to distinguish $\beta$-Fe$_2$O$_3$ from $\alpha$-Fe$_2$O$_3$, since the intensity peaks of (104) and (110) of $\alpha$-Fe$_2$O$_3$ appear at the similar positions of the (222) peak of $\beta$-Fe$_2$O$_3$ and the (311) peak of $\gamma$-Fe$_2$O$_3$, respectively. Although our previous papers have expected the co-existence of both $\gamma$-Fe$_2$O$_3$ and $\alpha$-Fe$_2$O$_3$, recent papers assigned both $\gamma$-Fe$_2$O$_3$ and $\beta$-Fe$_2$O$_3$ in the iron oxides prepared by calcining the PB. Still, detailed characterization is required to clarify this point. Increase of calcination temperature to 450 °C is observed to strengthen the most intensity peak of $\beta$-Fe$_2$O$_3$, suggesting that $\beta$-Fe$_2$O$_3$ phase increasingly becomes dominant at higher calcination temperatures.

The specific surface area, pore volume and pore size distribution of the iron oxide cubes prepared at different calcination temperatures were investigated by nitrogen (N$_2$) adsorption-desorption measurements (Figure 3c). The textural characteristics of the iron oxide cubes are summarized in Table 1. The specific surface areas of PB-250, PB-350, and PB-450 are 62.6, 99.8, and 54.8 m$^2$ g$^{-1}$, respectively. The smaller surface area of PB-250 compared to PB-350 is attributed to the incomplete removal of the cyanide ligand at 250 °C (Figure 1). On the other hand, the specific surface area of PB-450 is significantly lower than that of PB-350 at 54.8 m$^2$ g$^{-1}$, which may be attributed to the partial breakage or collapse of the cubes, as seen in Figure 2d. The peak of the pore size of the samples slightly increases from 3.28 nm to 4.76 nm with the increase of calcination temperature from 250 °C to 450 °C (Figure 3d). It is expected that the iron oxide cubes with the higher surface area can accept a higher loading of Au NPs with improved dispersion or separation between the Au NPs.

Inspired by their nanoporous structure and uniform morphology, the nanoporous iron oxide cubes (PB-350) with the highest surface area were selected for loading the Au NPs via the DP method and used as catalysts for CO oxidation at room temperature (The resulting sample is abbreviated as Au/PB-350). The morphology of the iron oxide cubes after the deposition of Au NPs was observed by SEM. From Figure 4a, it can be observed that all the cubes are well covered with Au NPs while preserving the cubic shape. TEM imaging was utilized for further morphological investigation, as shown in Figure 4b-c. Au NPs with an average size of 2 nm were well dispersed on the surface and interior of the iron oxide NCs. The high-resolution TEM (HRTEM) of Au/PB-350 reveals well-defined lattice fringes with a $d$-spacing of 0.25 nm and 0.23 nm, corresponding to the $d$-spacing of
(311) plane of $\gamma$-Fe$_2$O$_3$ and (111) plane of Au, respectively (Figure 4c). Selected area electron diffraction (SAED) patterns of the Au/PB-350 sample reveal its polycrystalline nature as indicated by the ring-like pattern (Figure 4d). The ED patterns can be assigned to $\gamma$-Fe$_2$O$_3$ which is the main phase in the obtained product. The presence of Fe, O, Au and the good dispersion of Au nanoparticles are confirmed using TEM elemental mapping, as shown in Figure 5. Furthermore, the elemental maps of C and N of Au/PB-350 clearly show the negligible amount of these elements, thereby indicating the complete removal of the C-N ligand of PB in this sample. The amount of Au loading on the Au/PB-350 was determined using ICP analysis. As shown in Table 2, the PB-350 can be successfully loaded with 11.02 wt.% of Au NPs. In contrast, as reported in our previous works$^{7,27}$, the commercial iron oxide sample could only be loaded with a small amount of Au NPs (0.81 wt.%) with the same loading procedure because of its non-porous structure and the fact that Au NPs cannot adsorb as easily on a flat metal oxide surface.

Following the Au-loading onto the nanoporous iron oxide cubes, CO oxidation tests were performed in the presence of these catalysts under a similar gas hourly space velocity (GHSV). The Au/PB-350 sample shows high CO conversion of over 95% under 0.1 L min$^{-1}$ of GHSV. In contrast, the Au-loaded commercial iron oxide catalyst displays a poor CO conversion rate of 28%.$^{27}$ As shown in Figure 6, when the GHSV was increased to 0.2 L min$^{-1}$, the CO conversion rate was slightly decreased slightly, although the conversion rate was kept above 80%. However, the CO conversion rate was dramatically reduced to around 30 % when the GHSV was increased to 1 L min$^{-1}$, and it was further reduced to between 10 to 20 % when the GHSV was further doubled to 2 L min$^{-1}$. The considerable decrease in CO conversion rates of these catalysts with increasing GHSV is caused by the reduced residence time of the reactants on the surface of these catalysts at higher GHSV.$^{27,41}$

The specific catalytic activities of the Au-loaded mesoporous iron oxide cubes were calculated and compared with previously reported catalysts as shown in Table 2. The Au/PB-350 catalyst exhibits a good catalytic activity for CO oxidation at 1.79 mol$_{\text{CO}}$·g$_{\text{Au}}^{-1}$·h$^{-1}$. In comparison, the specific activity of the Au/commercial iron oxide catalyst is lower at 1.46 mol$_{\text{CO}}$·g$_{\text{Au}}^{-1}$·h$^{-1}$. Furthermore, from Table 2, it can be observed that the Au/PB-350 catalyst shows better catalytic activity than Au-loaded commercial Fe$_2$O$_3$$^{27}$ and some previously reported oxide-supported Au catalysts.$^{7,17,27,41-46}$
Although the elucidation of the mechanism of CO oxidation over oxide-supported Au NPs is still unclear, the general consensus is that the active sites for CO oxidation are located at the interface between Au NPs and the iron oxide support and at the defect sites (e.g., steps, edges, corners, and kinks).\cite{7,47} The PB-derived nanoporous iron oxide cubes possess more defect sites compared to non-porous support materials, such as the commercial iron oxide. As a result, in addition to the surface of the iron oxide cubes, oxygen species can also adsorb at the defect sites and this leads to a higher CO conversion to CO$_2$ compared to the Au-loaded commercial iron oxide catalyst.\cite{48-49} Moreover, the nanoporous structure enable the Au NPs to be dispersed more uniformly throughout the cubes without serious aggregation in spite of the high Au loading, as seen in Figures 4 and 5. As a result, there is a more intimate contact between the iron oxide support and the deposited Au NPs. Furthermore, smaller Au NPs also provide a greater amount of reaction sites compared to larger Au NPs. In addition, nanoporous iron oxide supports can interact with CO molecules not only on their outer surface but also within their interior surface and the presence of nanopores can also improve the diffusivity of the reactants during CO oxidation, ultimately leading to higher CO conversion.\cite{41} Another potential reason for the high catalytic activity of these catalysts for CO oxidation is the size range of the deposited Au NPs (2-5 nm) which falls within the ideal size of Au NPs for achieving the maximum catalytic activity for CO oxidation (3.5 nm).\cite{50} Thus, it is clear that the utilization of nanoporous metal oxides as support materials for Au NPs provides many benefits compared to non-porous oxides.
Conclusions

We have successfully synthesized nanoporous iron oxide cubes by utilizing PB cubes as a sacrificial template and subsequently deposited Au NPs with ideal sizes of 2-5 nm onto the iron oxide matrix using the deposition-precipitation method. The nanoporous architecture with high surface area of the PB-derived iron oxide cubes enable successful high loading of Au NPs of up to 11 wt.% without serious aggregation. When tested as catalysts for CO oxidation, all the Au-loaded nanoporous iron oxide cubes display high CO conversion of over 95% even at room temperature under CO gas flow of 0.1 L·min⁻¹ and a humidity level of 60 %, with specific activity of up to 1.79 mol_CO·g_Au⁻¹·h⁻¹. The outcome of this study will promote and encourage the use of MOFs or PCPs as viable precursors for the derivation of nanoporous oxide supports for the deposition of noble metal NPs to be used in various catalytic reactions.
Experimental Section

**Chemicals.** PVP (Polyvinylpyrrolidone) (K30, \(M_w=40000\)) was purchased from Nacalai Tesque. Potassium hexacyanoferrate(III) (K₃[Fe(CN)₆]·3 H₂O), gold(III) chloride trihydrate (HAuCl₄·3H₂O, 99.99%), sodium hydroxide (NaOH, 98%), and hydrochloric acid (HCl, 37 wt.% in H₂O) were purchased from Wako Chemical Industries, Ltd. All the chemicals were used as received without further purification.

**Synthesis of Au-loaded nanoporous iron oxide cubes (NCs).** The nanoporous iron oxide cubes were prepared according to our previous report.\(^{[51]}\) In a typical process, 6.0 g of PVP (polyvinylpyrrolidone) (K30) and 264 mg of K₃[Fe(CN)₆]·3H₂O were dissolved in 80.0 mL of 0.01 M HCl aqueous solution under magnetic stirring. After the solution became clear yellow, the vial was placed into an electric oven and heated at 80 °C for 30 h. After cooling down to room temperature, the precipitate was collected by centrifugation and washed with DI water and ethanol for several times and subsequently dried at room temperature for 24 h. Following this, the PB powder was placed into an alumina crucible and heated in air at the designated temperatures (250 °C, 350 °C, 450 °C) under a slow a heating rate of 1 °C min⁻¹. The samples calcined at 250 °C, 350 °C, 450 °C were labeled as PB-250, PB-350 and PB-450, respectively. Deposition-precipitation method was utilized to load Au NPs onto the porous iron oxide nanocubes according to our previous report.\(^{[7]}\) Since the surface area of PB-350 is higher compared to PB-250 and PB-450, PB-350 was used for loading the Au NPs. In a typical procedure, 5 mM of HAuCl₄ was firstly dissolved in 100 mL of water. The solution was then heated to 70 °C and the pH was adjusted to 7 with the proper amount of NaOH solution. After cooling down to 15 °C, 50 mg of the PB-350 were added into the solution. The suspension was then stirred for 1 h at 70 °C and subsequently washed with distilled water for several times. Finally, the suspension was dried up under vacuum for overnight and the dried powder was subsequently calcined in air to obtain the Au-loaded mesoporous iron oxide NCs. The Au-loaded PB-350 was labeled as Au/PB-350.

**CO oxidation catalyst test.** In a typical procedure, 4 mg of the catalyst is inserted into a U-shaped glass tube and then heated to 250 °C under 0.1 L min⁻¹ of air flow for 30 min. Next, 1000 ppm of CO in air (0.1 vol% CO) was supplied into the tube at a controlled flow rate and the catalytic reaction was performed at 25 °C and a humidity level of 60 %. The rate of CO conversion was calculated from the change in the CO concentration.
after contacting the catalyst according to the equation:

\[
\text{CO conversion (\%)} = \frac{[\text{CO}]_{\text{in}} - [\text{CO}]_{\text{out}}}{[\text{CO}]_{\text{in}}} \times 100\% \quad (1)
\]

In order to study the effect of flow rate on the CO conversion, the CO gas flow rate was adjusted from 0.1 L min\(^{-1}\) to 2 L min\(^{-1}\).

**Characterizations.** The morphological examination of the samples was performed using scanning electron microscope (SEM) (Hitachi SU-8000) operated at an accelerating voltage of 5 kV and transmission electron microscope (TEM) (JEOL JEM-2100F) operated at an accelerating voltage of 200 kV. The purity and phase composition of the samples were analyzed by X-ray diffraction (Shimadzu XRD-7000) with Cu-K\(\alpha\) (\(\lambda=1.54\) Å). Thermogravimetric analysis (TGA) of the PB cubes was performed from room temperature to 800 \(^\circ\)C under air atmosphere and a heating rate of 10 \(^\circ\)C min\(^{-1}\) using a Hitachi HT-Seiko Instrument Exter 6300 TG. Inductively coupled plasma optical emission spectrometry (ICP-OES) measurements of the Au-loaded nanoporous iron oxide cubes were performed using a Hitachi model SPS3520UV-DD. Nitrogen (N\(_2\)) adsorption-desorption measurements were performed with a Belsorp-mini II Sorption System at 77 K to analyze the textural characteristics of the samples. Before the measurement, each sample was degassed at 120 \(^\circ\)C for 16 h. The specific surface areas and pore size distribution of the samples were evaluated using the multipoint Brunauer-Emmett-Teller (BET) and Barrett-Joyner-Halenda (BJH) methods, respectively.
References


Table 1. Textural characteristics of the PB-derived nanoporous iron oxide cubes obtained at different calcination temperatures

<table>
<thead>
<tr>
<th>Sample</th>
<th>Calcination temperature (°C)</th>
<th>Phase composition</th>
<th>Specific surface area (m² g⁻¹)</th>
<th>Pore volume (cm³ g⁻¹)</th>
<th>Peak pore size (nm)</th>
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</thead>
<tbody>
<tr>
<td>PB-250</td>
<td>250</td>
<td>γ-Fe₂O₃/α-Fe₂O₃</td>
<td>62.6</td>
<td>0.368</td>
<td>3.28</td>
</tr>
<tr>
<td>PB-350</td>
<td>350</td>
<td>γ-Fe₂O₃/α-Fe₂O₃</td>
<td>99.8</td>
<td>0.502</td>
<td>3.28</td>
</tr>
<tr>
<td>PB-450</td>
<td>450</td>
<td>γ-Fe₂O₃/α-Fe₂O₃</td>
<td>54.8</td>
<td>0.402</td>
<td>4.76</td>
</tr>
</tbody>
</table>

Table 2. Specific activities of the as-prepared PB-derived Au-loaded nanoporous iron oxide cubes for CO oxidation and comparison with previously reported Au/Fe₂O₃ catalysts.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Catalyst amount (g)</th>
<th>Au loading (wt%)</th>
<th>Specific activity (mol CO g⁻¹ h⁻¹)</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Au/PB-350</td>
<td>0.004</td>
<td>11.01</td>
<td>1.79</td>
<td>This work</td>
</tr>
<tr>
<td>Au/commercial Fe₂O₃</td>
<td>0.004</td>
<td>0.81</td>
<td>1.46</td>
<td>27</td>
</tr>
<tr>
<td>Au/mesoporous Fe₂O₃</td>
<td>0.004</td>
<td>7.80</td>
<td>0.30</td>
<td>7</td>
</tr>
<tr>
<td>Au/α-Fe₂O₃</td>
<td>0.5</td>
<td>0.50</td>
<td>0.12</td>
<td>41</td>
</tr>
<tr>
<td>Au/Fe₂O₃</td>
<td>0.04</td>
<td>1.00</td>
<td>0.94</td>
<td>43</td>
</tr>
<tr>
<td>Au/α-Fe₂O₃-C</td>
<td>0.05</td>
<td>2.90</td>
<td>0.40</td>
<td>42</td>
</tr>
<tr>
<td>Au/γ-Al₂O₃</td>
<td>n/a</td>
<td>1.00</td>
<td>1.62</td>
<td>45</td>
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<tr>
<td>Au/γ-Al₂O₃</td>
<td>0.15</td>
<td>0.17</td>
<td>0.022</td>
<td>46</td>
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<tr>
<td>Au/mesoporous TiO₂</td>
<td>n/a</td>
<td>27.8</td>
<td>0.37</td>
<td>17</td>
</tr>
<tr>
<td>Au/CeO₂</td>
<td>0.10</td>
<td>5.70</td>
<td>0.005</td>
<td>44</td>
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</tbody>
</table>
Figure 1 TGA curve of the PB cubes from room temperature to 800 °C under air atmosphere with a heating rate of 10 °C min\(^{-1}\).
Figure 2 SEM images of (a) PB NCs, (b) PB-250, (c) PB-350 and (d) PB-450.
Figure 3 XRD patterns of (a) PB NCs and (b) calcined PB NCs (PB-250, PB-350, and PB-450) and (c) the corresponding N$_2$ adsorption/desorption isotherms and (d) BJH pore size distribution curves.
Figure 4 (a) SEM image, (b) TEM image, (c) high resolution TEM (HR-TEM), and (d) selected area electron-diffraction (ED) patterns of the Au-loaded mesoporous iron oxide cubes (Au/PB-350).
Figure 5 (a) High angle annular dark field (HAADF) TEM image of the Au-loaded mesoporous iron oxide cubes (Au/PB-350), and the corresponding EDS mapping for (b) Fe, (c) O, (d) Au, (e) C, and (f) N.
Figure 6 The influence of CO gas flow rate on the CO conversion of Au/PB-350 at 25 °C.
GRAPHICAL ABSTRACT

Gold nanoparticles supported on Prussian blue-derived nanoporous iron oxide cubes exhibit high CO conversion of over 95 % at room temperature.