



# The Study on the Performance of Carbon Supported PtSnM (M = W, Pd, and Ni) Ternary Electro-Catalysts for Ethanol Electro-Oxidation Reaction

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PtSn/C and Pt<sub>5</sub>Sn<sub>4</sub>M/C (M = W, Pd, Ni) electrocatalysts were prepared by impregnation method using NaBH<sub>4</sub> as a reducing agent. Chemical composition, crystalline size, and alloy formation were determined by EDX, XRD and TEM. The average particle sizes of the synthesized catalysts were approximately 3.64~4.95 nm. The electro-chemical properties were measured by CO stripping, cyclic voltammetry, linear sweep voltammetry, and chronoamperometry. The maximum specific activity of the electro-catalysts for ethanol electro-oxidation was 406.08 mA m<sup>-2</sup> in Pt<sub>5</sub>Sn<sub>4</sub>Pd/C. The poisoning rate of the Pt<sub>5</sub>Sn<sub>4</sub>Pd/C (0.0017% s<sup>-1</sup>) was 4.5 times lower than that of the PtSn/C (0.0076% s<sup>-1</sup>).

**Keywords:** Electrochemical Catalyst, Ethanol Oxidation Reaction, Ternary Catalysts, Bi-Functional Mechanism, Co Tolerance Property.

## **1. INTRODUCTION**

In recent years, the direct ethanol fuel cell (DEFC) has been studied extensively because of high energy density (8.01 kWh/kg) and environment-friendly property as compared with other liquid fuels such as methanol (6.09 kWh/kg).<sup>1</sup> However, the slow reaction kinetics and inefficient conversion of ethanol to CO<sub>2</sub> are still the main obstacles for its application in a direct fuel cell since complete oxidation of ethanol involves many reaction steps consisted of C–C bond splitting, –OH formation form water activation, and oxidation of CO and CH<sub>x</sub> intermediates into CO<sub>2</sub>.<sup>2–4</sup> Furthermore, the reaction mechanism of the anodic oxidation is still not clearly understood.

To date, Pt has been shown to be the only active and stable single metal catalyst for the electro-oxidation of ethanol in acidic media. Pt is readily poisoned and rendered inactive by reaction intermediates such as CO.<sup>5</sup>

In order to increase the electrocatalytic activity of Pt towards ethanol oxidation, bimetallic alloyed catalysts such as such as PtRu,<sup>6,7</sup> PtSn,<sup>8-10</sup> PtW,<sup>11</sup> PtRh,<sup>12</sup> and PtMo<sup>13</sup> have been reported. Fortunately, incorporation of second metal could significantly improve catalytic activities due to improved CO tolerance property of Pt by producing –OH species to reaction with Pt–CO, the so-called "bi-functional mechanism."<sup>4, 14, 15</sup> Among these catalysts, PtSn is generally considered as the best material for ethanol oxidation.<sup>16, 17</sup> Recently, promoting effect of third metal incorporation such as Pt–Sn–M system has been reported while promoting mechanism of improved CO tolerance and ethanol oxidation by adding third metal is not fully defined.<sup>16, 18</sup>

Ribeiro et al.<sup>16</sup> have studied the effect of tungsten on PtSn/C catalysts for ethanol oxidation with XRD results showing that the electrocatalysts consisted of the Pt displaced phase, suggesting the formation of a solid solution between the Pt/W and Pt/Sn metals. The electrochemical tests of the electrocatalysts showed the PtSnW/C catalyst displaying better catalytic activity for ethanol

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oxidation compared to PtW/C. Furthermore, at 90 °C, the  $Pt_{85}Sn_8W_7/C$  catalyst gave higher current and power performances as an anode material in a direct ethanol fuel cell. Colmati et al.<sup>18</sup> investigated the electro-oxidation of ethanol on ternary PtSnRh (1:1:0.3 and 1:1:1) catalysts using a formic acid process and compared with PtSn and PtR. From linear sweep voltammetry (LSV), for potentials greater than 0.45 V (vs. RHE), the PtSnRh catalysts showed the highest activity for ethanol electro-oxidation, while for potentials lower than 0.45 V (vs. RHE), it was lower than that of the PtSn catalyst.

In this paper, ternary alloy electrocatalysts such as the  $Pt_5Sn_4M_1$  system (M = W, Ni, Pd) were synthesized by an impregnation method with NaBH<sub>4</sub> and designated  $Pt_5Sn_4W_1$ ,  $Pt_5Sn_4Ni_1$ , and  $Pt_5Sn_4Pd_1$ , respectively. For comparison, a PtSn catalyst was also synthesized using the same method. Physical properties were analyzed by transmission electron microscopy (TEM), X-ray diffraction (XRD), energy dispersive X-ray (EDX). Electrochemical properties using a three-electrode half-cell were characterized by CO stripping, cyclic voltammetry, linear sweep voltammetry, and chronoamperometry.

### 2. EXPERIMENTAL DETAILS

Electro-catalysts are synthesized using a conventional impregnation method and chemically reduced using sodium borohydride (NaBH<sub>4</sub>). Vulcan XC72R is dispersed in a mixture of de-ionized water and isopropyl alcohol, followed by sonication for 30 min. Metal precursors are then dissolved in the mixture. The H<sub>2</sub>PtCl<sub>6</sub> · xH<sub>2</sub>O (Kojima Chem. Co., City, Country), SnCl<sub>3</sub> · 2H<sub>2</sub>O (Aldrich Chem. Co., City, State, Country), WCl<sub>6</sub> (Aldrich), PdCl<sub>2</sub> (Aldrich), and NiCl<sub>2</sub> · 6H<sub>2</sub>O (Aldrich) are used as the Pt, Sn, W, Pd, and Ni precursors, respectively. The amounts of metal precursors are adjusted to give a total metal content in the catalyst of 60 wt%. After the mixture is heated and stirred for 1 h, it is reduced with a 0.2 mol% NaBH<sub>4</sub> solution for 3 h, filtered, and washed with hot de-ionized water. Finally, the samples are dried overnight at 80 °C.

X-ray diffraction (XRD) patterns are recorded on a Rigaku DMAX-2500 using a Cu K $\alpha$  radiation source and transmission electron microscopy (TEM) images of the synthesized catalysts collected using a JEM2200FS. Moreover, the compositions of the synthesized electro-catalysts are determined by energy dispersive X-ray (EDX) analysis using a JSM-6400.

Electrochemical measurements are carried out using a potentiostat (Bio-Logic, SP-150) at room temperature and at ambient pressure. Electrochemical studies are performed with a three electrode cell equipped with a Pt-wire counter electrode, Ag/AgCl reference electrode (BAS Co., Ltd., MF-2052 RE-5B), and a glassy carbon working electrode (3 mm diameter, BAS Co., Ltd., MF-2012). The working electrodes are prepared by the thin-film electrode

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method.<sup>19</sup> The catalysts are subjected to cyclic voltammetry (CV), CO stripping, linear sweep voltammetry (LSV), and chronoamperometry tests. The CV test is scanned in a potential range of 0.05-0.8 V (vs. reference hydrogen electrode (RHE)) at a rate of 15 mV s<sup>-1</sup>. Nitrogen purged 1.0 M  $H_2SO_4 + 1.0$  M EtOH solution is used as an electrolyte. CO stripping test is measured in a 1.0 M H<sub>2</sub>SO<sub>4</sub> solution at a scan rate of 15 mV s<sup>-1</sup>: CO is bubbled through the working electrode for one hour, while maintaining a constant voltage of 0.1 V (vs. RHE). The electrolyte is then purged by nitrogen gas  $(N_2)$  bubbling for 50 minutes to remove dissolved CO in the electrolyte. LSV tests are recorded at a scan rate of 5 mV  $s^{-1}$  between 0.05 V and 0.8 V. Chronoamperometry tests are carried out at 0.5 V for one hour in a solution of 1.0 M  $H_2SO_4$  + 1.0 M EtOH to evaluate the electro-catalytic activity of the electro-catalysts and poisoning of the active surface under continuous operation conditions. All potentials in this study are converted to RHE scale.

## 3. RESULTS AND DISCUSSION

XRD results of synthesized electro-catalysts are shown in Figure 1. In all the diffractograms, a broad peak near 25° was associated with the (0 0 2) plane of the hexagonal structure of the carbon black support material. Peaks at  $2\theta$  values of 40°, 47°, and 67° were related to the (111), (200), and (220) planes of the face centered cubic (fcc) crystalline Pt and Pt alloys, respectively. Additionally, two peaks were observed at  $2\theta$  values of 34° and 52° which were identified as the cassiterite SnO<sub>2</sub> phase. Other diffraction peaks for a third metal such as Pd, W, and Ni in the XRD patterns were not observed. The diffraction peaks of the ternary electro-catalysts were shifted slightly to higher  $2\theta$  values compared to that of PtSn/C. The higher angle shifts of the Pt diffraction peaks revealed the formation of an alloy involving the incorporation of Sn and other transition



Figure 1. XRD patterns of PtSn/C,  $Pt_5Sn_4W/C$ ,  $Pt_5Sn_4Pd/C$ , and  $Pt_5Sn_4Ni/C$ .

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metal atoms into the fcc structure of Pt.<sup>16,20,21</sup> The average particle sizes were calculated using the Debye-Scherrer equation.<sup>22</sup> The (111) diffraction peak of crystallographic Pt plane was used for particle size calculation.

$$d = \frac{k\lambda}{\beta_{1/2}\cos\theta} \tag{1}$$

where *d* is the particle size (nm),  $\lambda$  is the wavelength of X-ray,  $\theta$  is the angle of the maximum peak,  $\beta_{1/2}$  is the width of the diffraction peak at half height, and *k* is a coefficient of 0.89 to 1.39 (0.9 here). Average particle sized were 4.95, 4.07, 3.64, and 4.31 nm for Pt<sub>1</sub>Sn<sub>1</sub>/C, Pt<sub>5</sub>Sn<sub>4</sub>W<sub>1</sub>/C, Pt<sub>5</sub>Sn<sub>4</sub>Pd<sub>1</sub>/C, and Pt<sub>5</sub>Sn<sub>4</sub>Ni<sub>1</sub>/C electro-catalysts.

Figure 2 shows TEM image of Pt<sub>1</sub>Sn<sub>1</sub>/C, Pt<sub>5</sub>Sn<sub>4</sub>W<sub>1</sub>/C, Pt<sub>5</sub>Sn<sub>4</sub>Pd<sub>1</sub>/C, and Pt<sub>5</sub>Sn<sub>4</sub>Ni<sub>1</sub>/C electro-catalysts. Uniform dispersion of the prepared catalysts, without agglomeration, was observed for the all catalysts. Moreover, the chemical compositions of the electro-catalysts were determined by EDX analysis. The EDX analysis showed that the determined compositions were quite similar to the purposed value. The atomic ratios among the metals were 51.19 (Pt):48.81 (Sn), 49.71 (Pt):41.61 (Sn):8.68 (W), 50.56 (Pt):39.60 (Sn):9.84 (Pd), and 48.98 (Pt):41.86 (Sn):9.16 (Ni) for PtSn/C, Pt<sub>5</sub>Sn<sub>4</sub>W/C, Pt<sub>5</sub>Sn<sub>4</sub>Pd/C, and Pt<sub>5</sub>Sn<sub>4</sub>Ni/C, respectively. Results of XRD and EDX analysis were listed in Table Ly Ingenta to: Nanya

Decrease of the on-set potential for CO electrooxidation was observed in the alloy catalysts from Figure 3. The on-set potentials of the  $Pt_1Sn_1/C$ , Pt<sub>5</sub>Sn<sub>4</sub>W<sub>1</sub>/C, Pt<sub>5</sub>Sn<sub>4</sub>Pd<sub>1</sub>/C, and Pt<sub>5</sub>Sn<sub>4</sub>Ni<sub>1</sub>/C electrocatalysts for CO electro-oxidation were 0.276, 0.227, 0.206, and 0.212 V, respectively. Among these electrocatalysts, Pt<sub>5</sub>Sn<sub>4</sub>Pd/C exhibited the lowest potential at 0.206 V for CO electro-oxidation. Friedrich et al.<sup>23</sup> reported that smaller platinum particles show more positive CO oxidation potentials in relation to polycrystalline Pt and large particles. From Table I, the synthesized catalysts showed nearly the similar particle size, indicating that the greater negative CO oxidation potential on the alloy catalyst is not due to different particle size. Lu et al.24 reported a Pt-Pd bimetallic system also exhibiting a high resistance against CO poisoning from the oxidation of formic acid. Ozturk et al.<sup>25</sup> reported PtPd/C catalysts with high CO tolerance property during ethanol oxidation. High CO tolerance of alloyed catalysts can be explained by the bifunctional mechanism suggesting the oxidation of CO poisoned surface by OH species. Synergistic effect of alloyed metal causes CO<sub>2</sub> formation from adsorbed Pt-CO.

Figure 4 shows the CO stripping results of the  $Pt_1Sn_1/C$ ,  $Pt_5Sn_4W_1/C$ ,  $Pt_5Sn_4Pd_1/C$ , and  $Pt_5Sn_4Ni_1/C$  electro-catalyst. The CO stripping experiments were used to estimate the electrochemically active surface area (EAS). Due to the strong adsorption of CO onto the



Figure 2. TEM images of (a) PtSn/C, (b)  $Pt_5Sn_4W/C$ , (c)  $Pt_5Sn_4Pd/C$ , and (d)  $Pt_5Sn_4Ni/C$ .

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Table I. Atomic ratios of in-house catalysts and crystalline size.

	D	etermined	Crystalline size	
Catalysts	Pt	Sn	Third metal	XRD
PtSn/C	51.19	48.81	_	4.95
Pt <sub>5</sub> Sn <sub>4</sub> W/C	49.71	41.61	8.68	4.07
$Pt_5Sn_4Pd/C$	50.56	39.60	9.84	3.64
Pt <sub>5</sub> Sn <sub>4</sub> Ni/C	48.98	41.86	9.16	4.31

Pt surface, the hydrogen adsorption–desorption on the Pt was completely blocked in the hydrogen region, indicating the presence of a saturated CO adlayer.<sup>26</sup> The electrochemically active surface areas of the electrocatalysts were calculated using Eq. (2),<sup>27, 28</sup> where  $Q_{co}$  is the charge for CO desorption electro-oxidation in the microcoulomb ( $\mu$ C) and *G* is the loading of the electrocatalyst in the electrode, assuming an adsorption charge of 420  $\mu$ Ccm<sup>-2</sup> for a CO monolayer.

$$S_{\rm EAS} = \frac{Q_{\rm CO}}{G \times 420(\mu {\rm Ccm}^{-2})} \tag{2}$$

The electrochemically active surface areas (EAS) of the electrocatalysts were 40.13, 37.53, 39.97, and 23.53 m<sup>2</sup>  $(g \cdot catal)^{-1}$  for PtSn/C, Pt<sub>5</sub>Sn<sub>4</sub>W/C, Pt<sub>5</sub>Sn<sub>4</sub>Pd/C, and Pt<sub>5</sub>Sn<sub>4</sub>Ni/C, respectively. The EAS of the PtSn/C estimated to be 40.13 m<sup>2</sup>  $(g \cdot catal)^{-1}$  was higher than the other alloy catalysts.

Figure 5 shows the representative CV results obtained with the  $Pt_1Sn_1/C$ ,  $Pt_5Sn_4W_1/C$ ,  $Pt_5Sn_4Pd_1/C$ , and  $Pt_5Sn_4Ni_1/C$  electro-catalysts in a mixture of 1.0 M H<sub>2</sub>SO<sub>4</sub> and 1.0 M EtOH. The ethanol electro-oxidation reaction (EOR)s of  $Pt_5Sn_4W_1/C$ ,  $Pt_5Sn_4Pd_1/C$ , and  $Pt_5Sn_4Ni_1/C$ were started at 0.25, 0.27, and 0.25 V, respectively. It is similar to that of the PtSn/C electro-catalyst (0.25 V). However, ternary electro-catalysts exhibited higher performance in maximum current densities of EOR than PtSn. The maximum current densities of EOR on  $Pt_1Sn_1/C$ ,  $Pt_5Sn_4W_1/C$ ,  $Pt_5Sn_4Pd_1/C$ , and  $Pt_5Sn_4Ni_1/C$  were 13.36,



39.18, 55.93, and 32.26 mA cm<sup>-2</sup>, respectively. The  $Pt_5Sn_4Pd_1/C$  showed the highest current density for the EOR among the prepared electro-catalysts due to high CO tolerance property. It is in agreement with CO stripping results.

Figure 6 shows the linear sweep curves for the EOR of synthesized electro-catalysts in the potential range between 0.05 and 0.8 V. The ternary electro-catalysts show higher EOR activities than PtSn/C. It is similar with CV results. The Pt<sub>5</sub>Sn<sub>4</sub>Pd<sub>1</sub>/C electro-catalyst had a lower on-set potential and higher current density than any of the other electrocatalysts. The current densities were converted into mass and specific activities. The current densities of all electro-catalysts are compared at 0.5 V in terms of EOR activity. The current densities of the electro-catalysts were 5.32, 15.12, 18.37, and 8.38 mA  $\rm cm^{-2}$  for  $\rm Pt_1Sn_1/C,$ Pt<sub>5</sub>Sn<sub>4</sub>W<sub>1</sub>/C, Pt<sub>5</sub>Sn<sub>4</sub>Pd<sub>1</sub>/C, and Pt<sub>5</sub>Sn<sub>4</sub>Ni<sub>1</sub>/C, respectively. The mass activities of Pt<sub>1</sub>Sn<sub>1</sub>/C, Pt<sub>5</sub>Sn<sub>4</sub>W<sub>1</sub>/C, Pt<sub>5</sub>Sn<sub>4</sub>Pd<sub>1</sub>/C, and Pt<sub>5</sub>Sn<sub>4</sub>Ni<sub>1</sub>/C were 4.70, 13.35, 16.23, and 7.40 A (g · catal)<sup>-1</sup>, respectively. Compared to the 117.13 mA m<sup>-2</sup> of the Pt<sub>1</sub>Sn<sub>1</sub>/C electrocatalyst, the specific activities of the electrocatalysts were 355.97, 406.08, and 314.67 mA  $m^{-2}$ for Pt<sub>5</sub>Sn<sub>4</sub>W<sub>1</sub>/C, Pt<sub>5</sub>Sn<sub>4</sub>Pd<sub>1</sub>/C, and Pt<sub>5</sub>Sn<sub>4</sub>Ni<sub>1</sub>/C, respectively. The  $Pt_5Sn_4Pd_1/C$  electro-catalyst had the highest specific activity among the other electro-catalysts. Specific activity of the Pt<sub>5</sub>Sn<sub>4</sub>Pd<sub>1</sub>/C was approximately 3.5 times higher than that of the  $Pt_1Sn_1/C$ . The electrochemical properties such as on-set voltage for CO oxidation, EAS, current density, mass activity, and specific activity are summarized in Table II.

Oxidizing ethanol to CO<sub>2</sub> can produce many intermediates, including CO<sub>ads</sub>, acetaldehyde, and acetic acid. These species can be strongly adsorbed onto the Pt active sites, thus poisoning the catalyst and significantly reducing reaction kinetics.<sup>30</sup> We carried out long-term chronoamperometry testst at 0.5 V for one hour to calculate the poisoning rate. Chronoamperometry results are shown in Figure 7. For comparison, the results are separately displayed by different time scales 600 s (a) and 3600 s (b). The initial currents for the EOR in chronoamperometry test were higher than those characterized by LSV at the same potential, due to the lower amounts of oxidized Pt surface  $(PtO_r)$  in the catalysts.<sup>31</sup> Furthermore, during the initial minutes, there was a sharp decrease in the current density. It is because of the formation of CO<sub>ads</sub> and other intermediate species, such as CH<sub>3</sub>OH<sub>ads</sub>, CHO<sub>ads</sub>, and OH<sub>ads</sub> during the ethanol oxidation reaction,<sup>32</sup> followed by a slow decrease in the current values during long time tests. The poisoning rate  $(\delta)$  of the catalysts were calculated using the following equation:33,34

$$\delta = \frac{100}{I_0} \times \left(\frac{dI}{dt}\right)_{t > 500 \text{ s}} (\% \text{s}^{-1}) \tag{3}$$

Figure 3. On-set voltages for CO electro-oxidation of PtSn/C (dash),  $Pt_5Sn_4W/C$  (dot),  $Pt_5Sn_4Pd/C$  (solid), and  $Pt_5Sn_4Ni/C$  (dash dot).

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where dI/dt is the slope of the linear portion of the current decay above 500 seconds and  $I_0$  is the current at the

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start of polarization, back extrapolated from the linear current decay. The poisoning rates were calculated with current densities until 600 and 3600 seconds. A summary of the calculated poisoning rates is listed in Table III. The poisoning rates of the electro-catalysts until 600 seconds decreased in the order of: PtSn/C (0.0176) > Pt<sub>5</sub>Sn<sub>4</sub>Ni/C (0.0155) > Pt<sub>5</sub>Sn<sub>4</sub>Pd/C (0.0092) > Pt<sub>5</sub>Sn<sub>4</sub>W/C (0.0057), respectively. However, until 3600 seconds, the poisoning rates decreased in the order of: PtSn/C (0.0076) > Pt<sub>5</sub>Sn<sub>4</sub>Ni/C (0.0035) > Pt<sub>5</sub>Sn<sub>4</sub>W/C (0.0020) > Pt<sub>5</sub>Sn<sub>4</sub>Pd/C (0.0017), respectively. The ternary catalysts also showed better stability than Pt<sub>1</sub>Sn<sub>1</sub>/C catalyst. Especially, the Pt<sub>5</sub>Sn<sub>4</sub>Pd<sub>1</sub>/C exhibited the lowest poisoning rate among other catalysts that was approximately 4.5 times lower than



Figure 5. Cyclic voltammetry (CV) curves for EOR in 1.0 mol%  $H_2SO_4 + 1.0$  mol% EtOH on the PtSn/C (dash),  $Pt_5Sn_4W/C$  (dot),  $Pt_5Sn_4Pd/C$  (solid), and  $Pt_5Sn_4Ni/C$  (dash dot).



Figure 6. Liner sweep voltammetry (LSV) curves for ethanol electrooxidation on PtSn/C (dash),  $Pt_5Sn_4W/C$  (dot),  $Pt_5Sn_4Pd/C$  (solid), and  $Pt_5Sn_4Ni/C$  (dash dot).

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<b>Table II.</b> Electrochemical properties of the PtSn/C, $Pt_5Sn_4W/C$ , $Pt_5Sn_4Pd/C$ , and $Pt_5Sn_4Ni/C$ electrocatalysts.							
Catalysts	On-set voltage for CO oxidation (V)	$\frac{S_{\rm EAS}}{({\rm m}^2/{\rm g}\cdot{\rm catal})}$	Current density at 0.5 V (mA/cm <sup>2</sup> )	Mass activity at 0.5 V (A/g·catal)	Specific activity at 0.5 V (mA/m <sup>2</sup> )		
PtSn/C	0.276	40.13	5.32	4.70	117.13		
Pt <sub>5</sub> Sn <sub>4</sub> W/C	0.227	37.53	15.12	13.35	355.97		
Pt <sub>5</sub> Sn <sub>4</sub> Pd/C	0.206	39.97	18.37	16.23	406.08		
Pt <sub>5</sub> Sn <sub>4</sub> Ni/C	0.212	23.53	8.38	7.40	314.67		

that of the  $Pt_1Sn_1/C$  catalyst. The enhanced EOR activity of  $Pt_5Sn_4Pd_1/C$  is originated from low on-set potential of CO oxidation. It is in good agreement with CO stripping results. In the previous study,  $Xu^{35}$  et al. reported that PtPd catalysts had showed enhancement in the performance towards EOR due to the high CO tolerance property. Additionally, Kadirgan et al.<sup>4</sup> and She et al.<sup>36</sup> reported the high CO tolerant property of Pd system. The formation of the OH<sub>ad</sub> species at lower potentials on the Pd surface can transform the CO-like poisoning species into CO<sub>2</sub> or other products on the Pt–Pd surface. These products could then be dissolved in water, thereby freeing the active sites for further electrochemical reaction.



Figure 7. Chronoamperometry curves of PtSn/C,  $Pt_5Sn_4W/C$ ,  $Pt_5Sn_4Pd/C$ , and  $Pt_5Sn_4Ni/C$ ; (a) until 600 s, (b) until 3600 s.

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Table III. Poisoning rate of the PtSn/C,  $Pt_5Sn_4W/C$ ,  $Pt_5Sn_4Pd/C$ , and  $Pt_5Sn_4Ni/C$  electrocatalysts.

	Poisoning rate (%s <sup>-1</sup> )			
Catalysts	~600 s	~3600 s		
PtSn/C	0.0176	0.0076		
Pt <sub>5</sub> Sn <sub>4</sub> W/C	0.0057	0.0020		
Pt <sub>5</sub> Sn <sub>4</sub> Pd/C	0.0092	0.0017		
Pt <sub>5</sub> Sn <sub>4</sub> Ni/C	0.0155	0.0035		

## 4. CONCLUSIONS

The  $Pt_1Sn_1/C$  and  $Pt_5Sn_4M_1/C$  (M = W, Pd, Ni) electrocatalysts were synthesized by an impregnation method using NaBH<sub>4</sub> as a reducing agent. The catalytic activities of the synthesized ternary electrocatalysts were measured via electrochemical experiments, including CO stripping, ethanol electro-oxidation, and chronoamperometry tests. For comparison,  $Pt_1Sn_1/C$  catalyst was characterized.

From the CO stripping and ethanol electro-oxidation, ternary electro-catalysts exhibited better performances than  $Pt_1Sn_1/C$  binary catalyst. The maximum specific activity of the electro-catalysts for ethanol electro-oxidation was 406.08 mA m<sup>-2</sup> in  $Pt_5Sn_4Pd_1/C$ . The poisoning rate of the  $Pt_5Sn_4Pd_1/C$  (0.0017% s<sup>-1</sup>) was 4.5 times lower than that of the  $Pt_1Sn_1/C$  (0.0076% s<sup>-1</sup>).

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