Interfacial Sites between Cobalt Nitride and Cobalt Act as Bifunctional Catalysts for Hydrogen Electrochemistry

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Supporting Information

ABSTRACT: Hydrogen (H₂) electrochemistry primarily consists of two reactions: hydrogen evolution reaction in water for H₂ production (HER) and hydrogen oxidation reaction in hydrogen fuel cells for H₂ utilization (HOR). The realization of future hydrogen economy necessitates the development of low-cost and competent electrocatalysts for both HER and HOR. Herein, we report that partial nitridation of cobalt nanoparticles on current collectors results in rich Co₂N/Co interfacial sites, which exhibit bifunctional activity for hydrogen electrochemistry, rivaling the state-of-the-art Pt counterparts tested under similar conditions. Our combined experimental and theoretical computation results demonstrate that Co₂N/Co interfacial sites not only possess optimal hydrogen adsorption energy but also facilitate water adsorption and dissociation on the catalyst surface, all of which are beneficial to the electrocatalytic performance for both HER and HOR. In addition, our Co₂N/Co electrocatalysts also demonstrate great tolerance against CO poisoning during long-term H₂ oxidation.

Along with the increasing attention to exploring and utilizing sustainable energy sources, hydrogen (H₂) electrochemistry has attracted intense interest as H₂ production and oxidation play pivotal roles in the future hydrogen economy. In order to be economically attractive, low-cost and competent electrocatalysts are indispensable for both H₂ evolution and oxidation reactions (HER and HOR). Even though platinum-group metals, including Pt, Ir, Pd, and Rh, are still the state-of-the-art electrocatalysts for HER probably due to the enormous interest in water splitting during the past decade; however, relatively less progress has been achieved in HOR even though HOR is a very important reaction for H₂ utilization in fuel cells. For example, a variety of metal nitride materials have been explored for electrocatalytic HER including Pt-decorated Ni₃N nanosheets, Co/Ni₃N nanorods, rodlike CoₓNiₓN N-doped carbon polyhedral, graphdiyne-wrapped Co₃N nanosheets, Co/Ni₃N nanowires, Co/Co₃N Janus nanoparticles embedded in N-doped carbon, core–shell Co₂P-CoN nanoparticles in N-...
doped carbon nanotubes,\textsuperscript{34} and \textit{Co}_4\textit{N} nanowires on carbon cloth.\textsuperscript{35} By creating heterostructures and tuning compositions, scientists have developed metal nitrides with much improved HER performance. However, most of the reported metal nitrides electrocatalysts require energy-intensive hydrothermal treatment, expensive metal organic framework (MOF) templates, and complex organic polymerization, impeding their large-scale production. Moreover, those reported metal nitride electrocatalysts still need relatively large overpotentials (68−190 mV) to deliver a HER benchmark current density of −10 mA cm\textsuperscript{-2} in neutral and alkaline electrolytes. Furthermore, the electrocatalytic HOR activity of metal nitrides has been barely investigated.\textsuperscript{23−25}

Recently, we reported a bifunctional electrocatalyst of \textit{Ni}_3\textit{N}/Ni for both HER and HOR by creating interfacial sites between \textit{Ni}_3\textit{N} and Ni. Such an interfacing strategy shows great promise in developing competent hydrogen electrodes for water electrolyzers and hydrogen fuel cells.\textsuperscript{36} However, it is unclear whether this strategy can be applied to construct other bifunctional transition metal-based electrocatalysts. Moreover, the relatively low hardness of nickel used in our previous work makes it difficult to be applied in producing structurally rigid electrodes,\textsuperscript{37} and the substrate nickel foam may also complicate the elucidation of the real performance of the active sites in \textit{Ni}_3\textit{N}/Ni. Hence, it is desirable to explore reactive inert, structurally flexible, and also low-cost electrode substrates with alternative electrocatalysts containing metal/compound interfaces.

Herein, we extend our interfacing strategy to the preparation of a bifunctional cobalt-based electrocatalyst and report that the interfacial sites between cobalt nitride and cobalt nanoparticles formed on cobalt foam (\textit{Co}_2\textit{N}/Co/CF) or carbon paper (\textit{Co}_2\textit{N}/Co/CP) exhibit superior bifunctional activity for hydrogen electrochemistry, rivaling that of Pt-based electrocatalysts evaluated under similar conditions. Our electrodeposition and nitridation steps can be carried out under atmospheric pressure in a facile and scalable manner, which is beneficial to the large-scale production of electrocatalysts. To the best of our knowledge, the resultant interfacial \textit{Co}_2\textit{N}/Co electrocatalyst demonstrates extraordinary catalytic HER performance superior to that of nearly all reported cobalt-based electrocatalysts for both HER and HOR. Density functional theory (DFT) computational results support the fact that \textit{Co}_2\textit{N}/Co interfacial sites bear suitable hydrogen and hydrogen-oxidation-reduction (HOR) sites.

Figure 1. (a) XRD pattern of \textit{Co}_2\textit{N}/Co/CF and the standard XRD patterns of \textit{Co}_2\textit{N} and Co (cubic and hexagonal phases) as reference. (b,c) High-resolution Co 2p (b) and N 1s (c) XPS spectra of \textit{Co}_2\textit{N}/Co/CF. (d,e) SEM images of \textit{Co}_2\textit{N}/Co/CF at different magnifications. (f) HRTEM image showing the \textit{Co}_2\textit{N} component in \textit{Co}_2\textit{N}/Co/CF. The inset is a FFT pattern. (g−i) HAADF-STEM and corresponding elemental mapping images of Co and N in \textit{Co}_2\textit{N}/Co/CF. Scale bars: (d) 500 μm; (e) 10 μm (500 nm in the inset); (f) 5 nm; and (g−i) 2.5 nm.
water adsorption energies and also facilitate water dissociation, all of which are believed to contribute to the overall activity of Co$_2$N/Co toward HER and HOR. Another exciting observation is that Co$_2$N/Co shows great tolerance to CO poisoning, which is widely known of plaguing Pt during long-term H$_2$ oxidation. The success of Co$_2$N/Co demonstrates an effective strategy of interfacing metals and metal compounds (e.g., metal nitrides) for enhanced hydrogen electrochemistry.

The synthesis of Co$_2$N/Co/CF started from the electrodeposition of highly porous cobalt nanoparticles on cobalt foam (Co/CF) followed by thermal nitridation in ammonia (see details in the Supporting Information). The X-ray diffraction pattern of Co$_2$N/Co/CF obtained from nitridation at 350 °C for 3 h is shown in Figure 1a (other samples are shown in Figures S1 and S2), indicating the presence of orthorhombic Co$_2$N, hexagonal Co, and cubic Co phases despite the background noise caused by the fluorescence interference of Co. The valence states of surface composition elements in Co$_2$N/Co/CF were probed via X-ray photoelectron spectroscopy (XPS). Figure 1b shows the high-resolution Co 2p XPS spectrum. The peaks at 780.1 and 796.3 eV can be assigned to Co-N, which are consistent with reported cobalt nitride. The broad peaks at 785.3 and 802.3 eV are satellite peaks. The peak at 781.2 eV is assigned to Co$^{3+}$ due to surface oxidation upon exposure to air. The peaks at 778.8 and 794.1 eV are ascribed to metallic Co 2p$_{3/2}$ and 2p$_{1/2}$, respectively, which is in agreement with those of pristine Co (Figure S3a,b). The Co 2p XPS results indicate the presence of both metallic cobalt and cobalt nitride in Co$_2$N/Co/CF. For the N 1s region (Figure 1c), the main peak observed at 396.8 eV can be ascribed to the nitrogen species in Co$_2$N, while the shoulder peak at 398.1 eV likely results from the residual NH moieties of incomplete reaction with NH$_3$.

The surface morphology of Co$_2$N/Co/CF was characterized by scanning electron microscopy (SEM) and compared to those of the parent Co/CF and pristine cobalt foam (CF). In contrast to the pristine CF with a smooth skeleton (Figure S4a,b), Co$_2$N/Co/CF displays a macroporous network structure of rough ligaments with numerous stacked particles over the skeleton surface (Figure 1d,e). Such a three-dimensional structure was mainly inherited from the parent Co/CF (Figure S4c,d). To further clearly identify the cobalt nitride phase among various polymorphs, a selected Co$_2$N crystal grain was characterized by high-resolution transmission electron microscopy (HRTEM). The well-resolved lattice fringes (Figure 1f) with interplanar spacing of 0.230, 0.210, and 0.196 nm measured through fast Fourier transform (FFT) correspond to the crystal planes of (020), (111), and (012) of Co$_2$N, respectively. The intersection angles between the two planes match very well with the theoretical values, which is direct evidence for the formation of orthorhombic Co$_2$N and also consistent with the XRD results. To identify the Co$_2$N/Co interfacial sites, a HRTEM image of the Co$_2$N/Co interfacial region in Co$_2$N/Co/CF was collected and is shown in Figure S5a. Two kinds of spots in FFT of the selected area can be identified: one set includes larger spots, and another set has smaller dots (Figure S5b). The FFT image from the selected larger spots (Figure S5c,d) indicates very crystalline metallic cobalt with its [111] zone-axis along the electron beam direction. However, the IFFT image from

![Figure 2. LSV curves of Co$_2$N/Co/CF, Pt/CF, and Co/CF for HER in 1.0 M KOH (a) and 1.0 M KPi (b). (c) LSV curves of Co$_2$N/Co/CF before and after 10 000 cycles at a scan rate of 100 mV s$^{-1}$ between 0 and −100 mV vs RHE in 1.0 M KOH. The inset shows the chronopotentiometry curves of Co$_2$N/Co/CF conducted at −10 and −100 mA cm$^{-2}$ without iR correction. (d) Comparison of overpotential requirements of selected HER electrocatalysts to deliver −10 mA cm$^{-2}$ for HER in 1.0 M KOH. All LSV curves were iR-corrected.](https://doi.org/10.1021/acsenergylett.9b00738)
the selected smaller dots (Figure S5e,f) clearly shows the formation of small Co$_2$N nanoparticles in a cobalt matrix with te zone-axis along [1−10]. In addition, scanning transmission electron microscopy (STEM) combined with energy-dispersive X-ray (EDX) mapping results obtained from the identical area is shown in Figures 1g−i and S6. Apparently, the nitrogen distribution in the composite is not uniform at the nanoscale, which indicates the presence of small nitride nanoparticles on the cobalt surface. EDX spectra from the selected areas (Figure S7) also show significantly different nitrogen contents in the different areas, even at the nanoscale. Collectively, these characterization results validate the formation of Co$_2$N on Co/CF, as well as Co$_2$N/Co interfacial sites in Co$_2$N/Co/CF.

Co$_2$N/Co/CF was first evaluated for its electrocatalytic H$_2$ evolution activity in both H$_2$-saturated alkaline (1.0 M KOH) and neutral (1.0 M potassium phosphate, KPi) electrolytes. All potentials reported herein are referenced to the reversible hydrogen electrode (RHE), and the reported current densities were normalized based on the geometric area of the electrode for the comparison of apparent activity. It should be noted that both nitridation temperature and duration were varied to achieve the optimized electrocatalyst, and it was found that nitridation at 350 °C for 3 h yielded a Co$_2$N/Co/CF sample with the best HER performance at both pH 7 and 14 (Figures S8−S11). Therefore, the Co$_2$N/Co/CF samples discussed in the following paragraphs were synthesized according to this optimized condition unless noted otherwise. For comparison, the pristine Co/CF and commercial Pt/C (20%) loaded on bare CF (Pt/CF) were also tested for catalytic HER under the same conditions. The loading mass of Pt/C was varied to achieve the best HER performance in both alkaline and neutral electrolytes (Figures S12 and S13). Figure 2a,b plots the linear sweep voltammery (LSV) curves of Co$_2$N/Co/CF, Pt/C, and Co/CF in 1.0 M KOH and KPi, respectively. In both alkaline and neutral electrolytes, Co$_2$N/Co/CF exhibited a catalytic HER takeoff at near-zero overpotential, similar to the benchmark Pt/CF. However, Co/CF required a much larger overpotential to initiate H$_2$ evolution. In 1.0 M KOH (Figure 2a), Co$_2$N/Co/CF was able to produce −10 and −100 mA/cm$^2$ at overpotential of merely 12 and 64 mV, respectively, substantially smaller than those required by Pt/CF (20 and 98 mV). At pH 7 (Figure 2b), Co$_2$N/Co/CF also exhibited excellent HER performance, demanding only 26 and 120 mV overpotentials to reach −10 and −100 mV/cm$^2$, which were apparently superior to Pt/CF tested under the same condition. The Tafel plots of Co$_2$N/Co/CF derived from their LSVs are shown in Figures S14 and S15. The Tafel slopes of Co$_2$N/Co/CF for HER in 1.0 M KOH and 1.0 M KPi were as low as 41.6 and 87.5 mV/decade, respectively, which are even smaller than those of Pt (73.3 and 108.5 mV/decade). These Tafel slopes of Co$_2$N/Co/CF indicate that the electrocatalytic HER kinetics likely follows the Heyrovsky mechanism (H$_2$O + M + H* + e$^- = M + H$_2$ + OH$^-$), where H* represents a hydrogen atom absorbed on a catalyst surface. The rate-limiting step of HER on Co$_2$N/Co/CF is closely related to the initial water dissociation and the subsequent H* adsorption.

The aforementioned HER performance based on the apparent current density could be overestimated for an electrocatalyst because of its highly porous structure. In order to make a fair comparison between Co$_2$N/Co/CF and the state-of-the-art Pt in electrocatalytic H$_2$ evolution, we further measured their respective electrochemically active surface area (ESCA) and normalized the obtained current against the corresponding ECSA of each catalyst. It should be noted that all of the ECSA measurements were conducted in anhydrous acetonitrile with the aim of excluding the impact of hydration and protonation commonly observed for first-row transition metal compounds in aqueous media. Although the ECSA of Co$_2$N/Co/CF is 2.38 times lower than that of Pt/CF (2.5 mg cm$^{-2}$) (Figure S16a−d), the ECSA-normalized current densities of Co$_2$N/Co/CF for HER are still much higher than those of Pt/CF in both alkaline and neutral electrolytes (Figures S17 and S18). Figures S19a,b and S20a,b show the Nyquist plots with fitting curves and an equivalent circuit model and the Bode plots of Co$_2$N/Co/CF and Co/CF for HER at given potentials in 1.0 M KOH and KPi. The fitting results are listed in Table S1, showing the much smaller charge transfer resistance and fast kinetics of HER on Co$_2$N/Co/CF than those on Co/CF in both basic and neutral electrolytes.

To demonstrate that the excellent HER performance of Co$_2$N/Co is independent of the underlying current collector, such as the cobalt foam, we further synthesized Co$_2$N/Co on carbon paper (Co$_2$N/Co/CP) following the same synthetic procedure of Co$_2$N/Co/CF except for replacing CF with carbon paper. A suite of characterizations (XRD, SEM, and XPS) were also conducted on Co$_2$N/Co/CP (Figures S21, S22a,b, and S23a−d) to confirm the presence of Co$_2$N/Co with similar composition and morphology as those of Co$_2$N/Co/CF. Figure S24 presents the LSV and chronopotentiometry curves of Co$_2$N/Co/CF compared to those of Co$_2$N/Co/CF. The near overlap of these curves proves that the great HER performance of Co$_2$N/Co does not rely on a particular current collector; instead, it most likely originates from the real active sites located on Co$_2$N/Co.

Besides intrinsic activity, long-term stability is another important criterion in assessing any catalysts. The robustness of Co$_2$N/Co/CF for extended H$_2$ evolution was evaluated via repetitive cyclic voltammetry (CV) and chronopotentiometry. As depicted in Figure 2c, after 10 000 CV cycles, the HER overpotential of Co$_2$N/Co/CF required to achieve −100 mA cm$^{-2}$ only increased by 7 mV in 1.0 M KOH. In addition, the stable chronopotentiometry curves collected at −10 and −100 mA/cm$^2$ for 100 h (Figure 2c inset) further corroborated its great robustness for long-term H$_2$ evolution. Similar stability was observed for Co$_2$N/Co/CF in neutral electrolyte (Figures S25 and S26). Postelectrolysis characterization revealed no apparent change in the morphology and composition of Co$_2$N/Co/CF (Figure S27a−d), implying its outstanding structural robustness and mechanical stability. Furthermore, the produced H$_2$ amount matched well the theoretically calculated quantity (Figure S28), which indicated that all of the passed charge was used to generate H$_2$, resulting in a nearly 100% Faradaic efficiency. Overall, to the best of our knowledge, Co$_2$N/Co/CF represents one of the most active HER electrocatalysts in alkaline and neutral electrolytes, surpassing a great number of reported nonprecious electrocatalysts (Figure 2d and Table S2).

Next, DFT computation was carried out to aid the understanding of the superior activity of Co$_2$N/Co/CF for H$_2$ production. We reasoned that a suitable model structure of Co$_2$N/Co is a few layers of Co$_2$N positioned on a Co basal plane. For a systematic comparison, three model systems with the lowest-energy surfaces of Co$_2$N(001), Co(001), and hybrid Co$_2$N/Co with a Co$_2$N(001) slab in contact with the Co(001) surface were considered. Due to the lack of free H* in neutral and alkaline electrolytes, the commencement of electrocatalytic
H₂ evolution at pH 7 and 14 demands water adsorption and dissociation on catalyst surface as the initial steps. The computed water adsorption energies on Co₂N/Co, Co₂N, and Co are compared in Figure 3a with their respective adsorption configurations shown in Figures S29a,b, S30a,b, and S31a,b, respectively. It is apparent that Co₂N/Co exhibits the strongest water adsorption among the three models, and the optimal water adsorption site is located at the interface between Co₂N and Co in Co₂N/Co with one of the H atoms in water approaching the edge N in Co₂N (Figure S32a,b), probably due to the hydrogen bond interaction. Such a configuration of water adsorption on Co₂N/Co is believed to be beneficial for its subsequent dissociation. Indeed, as shown in Figure 3b, the critical transition state of water dissociation has the lowest energy on Co₂N/Co. The detailed structure and energy of each state for water dissociation on Co₂N/Co, Co₂N, and Co can be found in the Supporting Information (Figures S32a,b S33a,b, S34a,b, and S35a,b). A widely accepted consensus in hydrogen electrochemistry is that hydrogen adsorption free energy (ΔG_{Had}) on an electrocatalyst is a key descriptor of its activity. A high catalytic performance is anticipated if ΔG_{Had} is close to 0 eV. Therefore, hydrogen adsorption on Co₂N/Co, Co₂N, and Co was also investigated computationally. The most plausible hydrogen adsorption sites on these models were considered (Figures S35−S44 and Table S3). The free energy changes of hydrogen adsorption at two interfacial sites of Co₂N/Co were calculated to be merely −0.02 and −0.04 eV, very close to the ideal value of 0 eV (Figure 3c,d). In contrast, both Co₂N and Co exhibit strong hydrogen affinity (−0.27 to −0.40 eV). Collectively, these DFT computational results demonstrate that the interfacial sites of Co₂N/Co can enhance water adsorption, facilitate water dissociation, and also exhibit optimal hydrogen adsorption energy, all of which contribute to its extraordinary HER activity.

Encouraged by the extremely small ΔG_{Had} value and nearly zero HER onset potential, we reasoned that Co₂N/Co could be a promising electrocatalyst for the reverse reaction of HER, the hydrogen oxidation reaction (HOR), as both HER and HOR share the same critical intermediate, adsorbed H (H_{ads}). The HOR performance of Co₂N/Co/CF was measured in H₂-saturated 0.1 M KOH electrolyte to mimic the alkaline condition of hydroxide exchange membrane fuel cells. Similar to HER, the best HOR activity was also obtained from Co₂N/Co/CF after nitridation at 350 °C for 3 h (Figures S45 and S46). Figure S47 compares the steady-state polarization curves of Co₂N/Co/CF collected in H₂- or Ar-saturated 0.1 M KOH in the same potential region of −0.06−0.1 V vs RHE. The apparent anodic current at positive potential (vs RHE) was obtained only in the presence of H₂, suggesting that H₂ oxidation takes place on Co₂N/Co/CF. Commercial Pt/C with optimized loading (1.5 mg cm⁻²) on CF (Pt/CF) was also included for comparison (Figure S48). As plotted in Figure 4a, the electrocatalytic HOR performance follows the order of Co₂N/Co/CF > Pt/CF > Co/CF. Co₂N/Co/CF showed a catalytic takeoff at 0 V vs RHE and produced higher current density than Pt/CF in the entire potential window (0−0.1 V vs RHE), even if the current density was normalized by their corresponding ECSA (Figure S49). In contrast, Co/CF displayed negligible catalytic activity for HOR, confirming that the enhanced HOR activity of Co₂N/Co/CF arises from the Co₂N/Co interfacial sites. In order to assess the intrinsic activity, the exchange current density was estimated from the micropolarization window from −10 to 10 mV vs RHE. Co₂N/Co/CF produced an exchange current density of −2.86 mA cm⁻², which was 1.4 and 28.5 times higher than that of Pt/CF and Co/CF, respectively (Figure S50). The stability of Co₂N/Co/CF for H₂ oxidation was further assessed by chronoaerometry at 0.05 V vs RHE in 0.1 M KOH electrolyte.

Figure 3. (a) Water adsorption energy on Co, Co₂N, and Co₂N/Co. (b) Reaction energetics for water dissociation on Co, Co₂N, and Co₂N/Co. (c) Optimized structures of H adsorption at two different positions of interfacial Co₂N/Co. Color code: pink (Co), blue (N), and white (H). (d) Free energy changes (ΔG_{Had}) of H adsorption on Co, Co₂N, and Co₂N/Co.
0.09 V vs RHE in 0.1 M KOH (Figure 4b), showing a stable current density of 4.5 mA cm$^{-2}$ in the presence of H$_2$, in striking contrast to the negligible capacitance current density obtained in the Ar-saturated KOH (Figure S51). Without nitridation, Co/CF only delivered no more than 0.1 mA cm$^{-2}$ in H$_2$-saturated 0.1 M KOH, in agreement with the crucial role of Co$_2$N/Co in catalyzing H$_2$ oxidation (Figure 4b). The excellent stability of Co$_2$N/Co/CF for H$_2$ oxidation was attributed to the robustness of Co$_2$N. Figures S52 and S53 present the XRD pattern and HRTEM image of Co$_2$N/Co/CF post HOR electrolysis, and the results indicate good retention of composition and retention of Co$_2$N/Co/CF after long-term electrolysis for H$_2$ oxidation in 0.1 M KOH. The XPS spectra of the postcatalysis Co$_2$N/Co/CF also exhibited little changes compared to that of pristine Co$_2$N/Co/CF (Figure S54).

Current industrial H$_2$ supply is mainly from steam reforming, producing cost-effective H$_2$ feeds yet with CO impurity, which is detrimental to Pt-based electrocatalysts. Therefore, a high CO tolerance is desirable for HOR electrocatalysts. Herein, a CO tolerance test was also carried out for Co$_2$N/Co/CF and Pt/CF using a H$_2$ gas mixture with 2% (v/v) CO. As shown in Figure 4c, the steady-state polarization curve of Co$_2$N/Co/CF showed no apparent degradation in the presence of CO, while Pt/CF indeed suffered from substantial CO poisoning. For instance, the anodic current density of Co$_2$N/Co/CF slightly decreased from 4.6 to 4.4 mA cm$^{-2}$ at 0.09 V vs RHE upon the addition of 2% CO in the H$_2$ feed (Figure 4d), whereas the current density of Pt/CF was dramatically reduced by 57%, decreasing from 4.15 to 1.79 mA cm$^{-2}$. Co$_2$N/Co/CF also exhibited a
much longer robustness than Pt/CF toward CO poisoning (Figure 4e). The anodic current density of Co2N/Co/CF remained at ca. 3.5 mA cm\(^{-2}\) after 6 h when electrolysis at 0.09 V vs RHE was carried out with a feed of 2% CO in H\(_2\), whereas a current density of only 0.7 mA cm\(^{-2}\) was produced on Pt/CF under the same condition.

In summary, we successfully constructed low-cost Co2N/Co electrocatalysts through a facile electrodeposition and nitridation approach. The interfacial sites of Co2N/Co exhibit excellent performance for both \(\text{H}_2\) evolution and oxidation reactions, rivaling the activity of Pt-based electrocatalysts evaluated under similar conditions. Together with its remarkable CO tolerance, Co2N/Co is a great catalyst candidate in the applications of water electrolyzers and alkaline hydrogen fuel cells. DFT calculations revealed the critical role of Co2N/Co interfacial sites in promoting the adsorption and dissociation of water and optimizing the free energy of hydrogen adsorption. This work showcases that interface construction between metals and metal nitrides is an effective strategy in developing competent catalysts for the hydrogen electrochemistry.

**REFERENCES**


**Author Contributions**

©F.S. and W.L. contributed equally to this work.

**Notes**

The authors declare no competing financial interest.

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