Sulfonated graphene oxide/Nafion composite membranes for high temperature and low humidity proton exchange membrane fuel cells

Supporting information

Fig. S1 Optical photographs of dissolution of Fe$_3$O$_4$ nanoparticles in 1 M H$_2$SO$_4$ at 70 °C at (a) 0 mins, (b) 30 mins, (c) 60 mins and inset (c) 90 mins; corresponding EDX spectra of remaining Fe$_3$O$_4$ nanoparticles at (d) 0 mins, (e) 30 mins and (f) 60 mins; EDX spectra of remaining Fe$_3$O$_4$-SGO composite after immersed in 1 M H$_2$SO$_4$ at 70 °C at (g) 0 mins, (h) 30 mins and (i) 60 mins.

Hydrolytic stability of GO, SGO and Fe$_3$O$_4$-SGO

In general, the performance of PEFC is strictly affected by metal/metal oxide leaching out from the composite PEM in an acidic environment. In present study, the hydrolytic stability of Fe$_3$O$_4$ and Fe$_3$O$_4$-SGO composite was measured in 1 M acidic solution (pH<1) at 70 °C to understand the dissolution of Fe$_3$O$_4$, as shown in Fig. S1. An amount of Fe$_3$O$_4$ or Fe$_3$O$_4$-SGO was added in 1 M H$_2$SO$_4$ (5 mg mL$^{-1}$) and the mixture was stirred at 70 °C for desired time. After dissolution, the remaining Fe$_3$O$_4$ nanoparticles were separated by magnetic bar, while Fe$_3$O$_4$-SGO was separated by filtration due to its trivial magnetic behavior. The stability of fillers was assessed from wt% of Fe in remaining sample at 30 mins intervals. The EDX spectra were collected at three different regions in each sample and displayed value is the average of data. It can be seen that Fe$_3$O$_4$ dissolves completely at 90 mins of time and rapid dissolution of
Fe$_3$O$_4$ may be due to the formation of corresponding hydroxides (Fig. S1c inset). After 60 mins of time, the wt% of Fe in Fe$_3$O$_4$ and SGO-Fe$_3$O$_4$ were found to decrease from 74.51 to 35.03 and from 35.61 to 28.21, respectively. These results indicate that the leaching of Fe$_3$O$_4$ is very less after anchoring over SGO surface. It is noteworthy to mention that Fe$_3$O$_4$ nanoparticles are surrounded by SGO sheets and held tightly in the matrix. Such geometric confinement enhances the interactions at the interface of Fe$_3$O$_4$ and SGO, thereby reducing the dissolution and aggregation of Fe$_3$O$_4$ nanoparticles in acidic environment. Furthermore, the extended sheets of SGO perform as barrier to prevent the direct contact of acid and Fe$_3$O$_4$ nanoparticles, which further reduces the dissolution of Fe$_3$O$_4$ nanoparticles in composite.
Scheme S1 Possible interactions exerted between Nafion and Fe₃O₄-SGO.
Table S1 Comparison of various Nafion composite membranes.

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<tr>
<th>Membrane</th>
<th>Proton conductivity (mS cm⁻¹)</th>
<th>Operating conditions</th>
<th>Peak power density (mW cm⁻²)</th>
<th>Peak current density (mA cm⁻²)</th>
<th>Operating conditions</th>
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