Graphene-based Cathodes for Low Temperature Solid Oxide Fuel Cell

Youngseok Jee, Hyeongjoo Moon, Min Hwan Lee*

School of Engineering, University of California, Merced

5200 N. Lake Rd, Merced, CA 95348 USA
mlee49@ucmerced.edu*

Recently, intense efforts have been made to lower the operating temperature of SOFC to minimize fabrication cost and material issues, and thus to broaden their applications.[1] However, reduction in operating temperature is followed by a significant sacrifice in electrode kinetics and ionic conductivity.[2] While sacrifice in ionic conductivity has been successfully supplemented by minimizing electrolyte thickness[1,3-5], sustaining decent electrode kinetics, especially oxygen reduction reaction (ORR) rate, at lower temperatures using conventional ceramic-based electrodes remains as a challenge. However, graphene-based electrodes such as nitrogen-doped graphene were recently found to show an excellent ORR catalytic activity comparable to that of Pt-based electrodes even at room temperature.[6] In addition, graphene is reported to have exceptional thermal stability up to at least 2600 K.[7] Motivated by these superior attributes of graphene, reduced graphene oxide (rGO) variants were applied to LT-SOFC as a cathode material.

As shown in Fig. 1a, ORR activities of rGO-based electrodes were first characterized by electrochemical impedance spectroscopy (EIS) in atmospheric air environment at various temperatures. Yttria-stabilized zirconia (YSZ) was used the electrolyte, and three different kinds of rGO variants (rGO, N-doped rGO and Pt nanoparticle incorporated rGO) were studied as electrode materials. The Faradaic resistances for ORR extracted from the resulting impedance spectra were plotted in Fig. 2. Although these rGO-based electrodes showed lower ORR activities than that of pure Pt electrodes by almost 1-2 orders of magnitude under a given temperature, the gap became negligible as the operation time elapses (data not shown). Although Pt have been unrivaled as a cathode material for low temperature catalysts, metal electrodes tend to degrade over time due to Ostwald ripening,[9] which again results in significant cell performance degradations. In the presentation, the full cell performances using these rGO-based electrodes will be presented as well (Fig. 1b).

It is also noted that all the rGO variants studied here suffered from an abrupt increase in the resulting Faradaic resistance at a temperature of >~400°C. It is attributed to the oxidation of rGO materials, and resulting change in its volume and the contact with the YSZ electrolyte. Although rGO variants may not be a stable material for operating > ~350°C, an ultra-thin electrolyte-based cell can be a viable solution to implement an LT-SOFC operating at a very low temperature (~300°C).

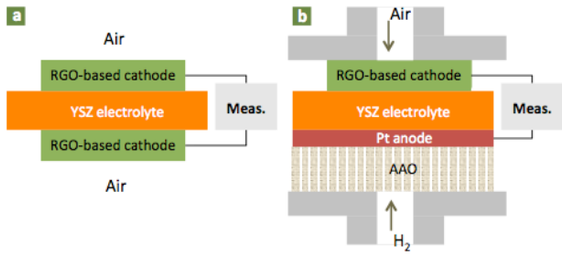

Figure 1. Simplified experimental setup for quantifying (a) ORR activities and (b) powering performances of the RGO-based electrodes

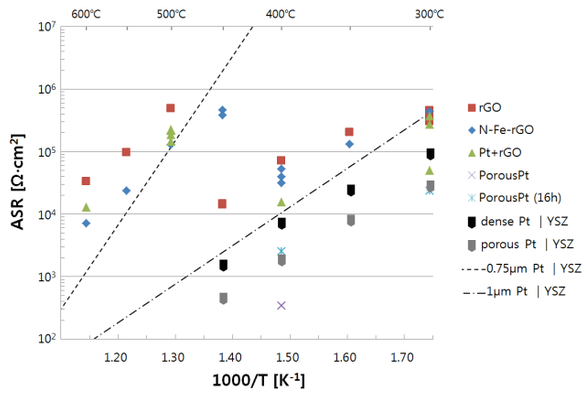

Figure 2. Arrhenius plot comparing ORR activities of rGO variants and Pt electrodes.

References

[1] Huang, H., *et al.* High-performance ultrathin solid oxide fuel cells for low-temperature operation. *Journal of the Electrochemical Society* **154**, B20-B24 (2007).
[2] Murray, E.P., Tsai, T. & Barnett, S.A. A direct-methane fuel cell with a ceria-based anode. *Nature* **400**, 649-651 (1999).
[3] Kang, S., Su, P.C., Park, Y.I., Saito, Y. & Prinz, F.B. Thin-film solid oxide fuel cells on porous nickel substrates with multistage nanohole array. *Journal of the Electrochemical Society* **153**, A554-A559 (2006).
[4] Muecke, U.P., *et al.* Micro Solid Oxide Fuel Cells on Glass Ceramic Substrates. *Advanced Functional Materials* **18**, 3158-3168 (2008).
[5] Su, P.C., Chao, C.C., Shim, J.H., Fasching, R. & Prinz, F.B. Solid oxide fuel cell with corrugated thin film electrolyte. *Nano Letters* **8**, 2289-2292 (2008).
[6] Sun, Y.Q., Wu, Q.O. & Shi, G.Q. Graphene based new energy materials. *Energy & Environmental Science* **4**, 1113-1132 (2011).
[7] Kim, K., *et al.* High-temperature stability of suspended single-layer graphene. *Phys. Status Solidi-Rapid Res. Lett.* **4**, 302-304 (2010).