Electronic Supplementary Material (ESI) for Nanoscale.

Electronic Supplementary Information

Nanoporous Silver by Pulsed Laser Deposition for High-Performance Oxygen Reduction Reaction and Hydrogen Peroxide Sensing

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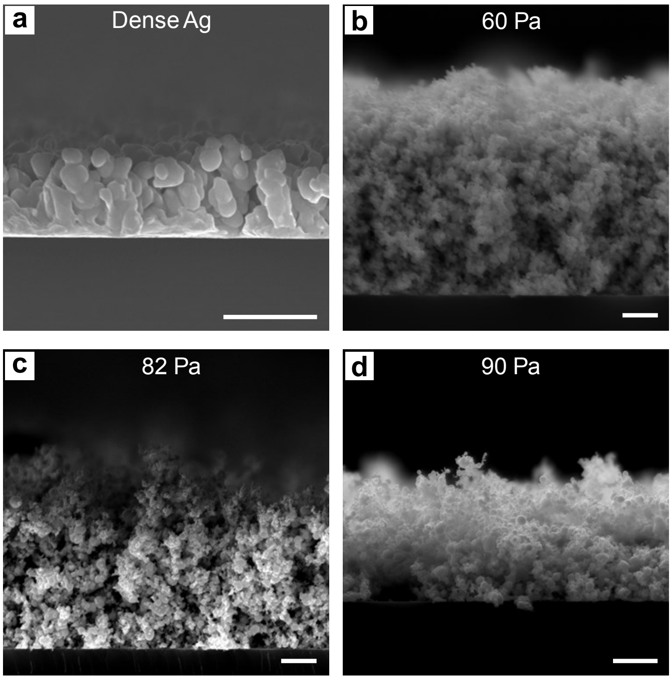

Figure S1. (a) SEM image of dense PLD-Ag. (b-d) SEM images of porous PLD-Ag deposited at different pressures of background gas: (b) 60 Pa; (c) 82 Pa; (d) 90 Pa (scale bars: 1 μm).

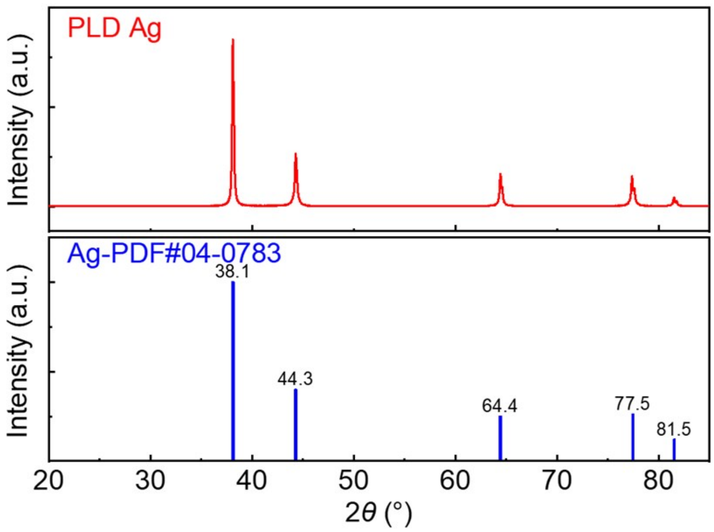

Figure S2. XRD spectrum of porous PLD-Ag (top) and standard XRD peaks of Ag (bottom).

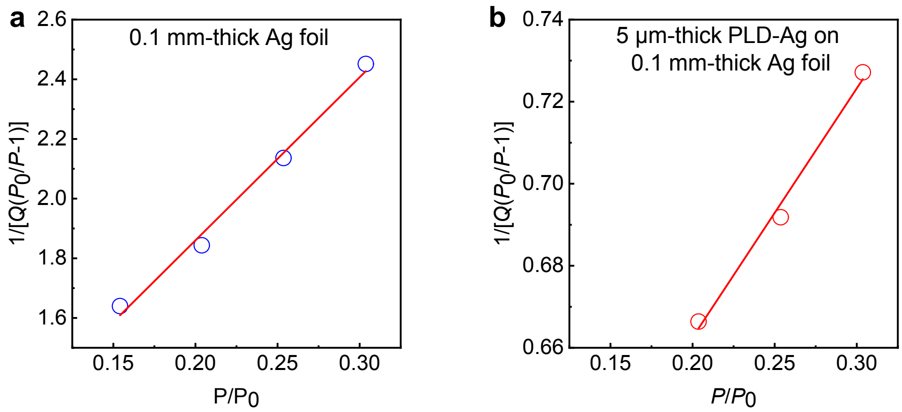

Figure S3. BET measurement results and BET surface area of (a) 0.1 mm-thick smooth Ag foil (BET surface area: 0.698 m²/g) and (b) 5 μm-thick PLD-Ag on 0.1 mm-thick smooth Ag foil (BET surface area: 3.790 m²/g).

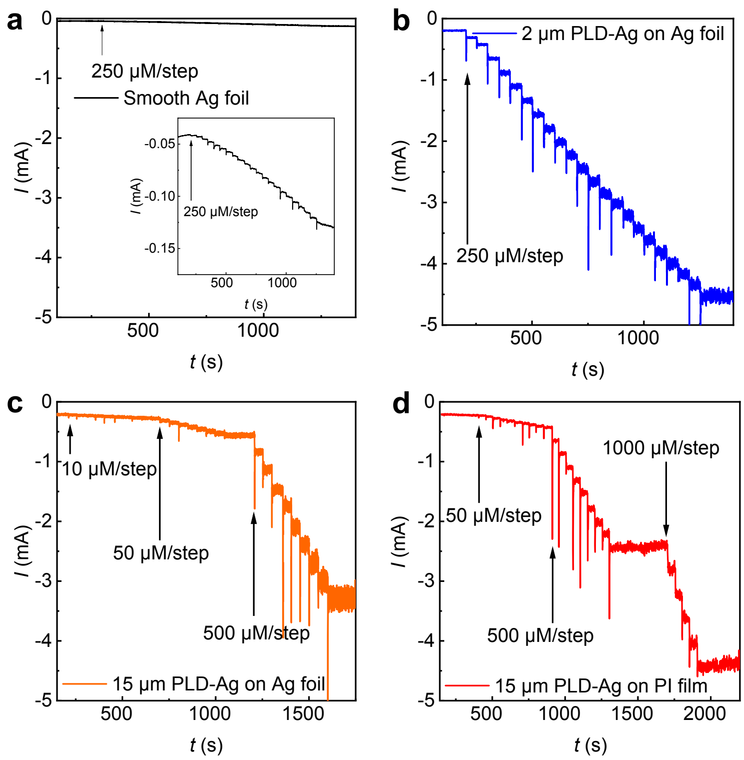

Figure S4. Current-time curves of (a) smooth Ag foil, (b) 2-μm porous PLD-Ag on Ag foil, (c) 15-μm porous PLD-Ag on Ag foil and (d) 15-μm porous PLD-Ag on PI film when certain amounts of H_2O_2 were added into PBS at -0.2V (*vs*. SCE).

Table S1. ORR performance of some reported Ag-based catalysts.

Catalysts	E_{onset}	$E_{1/2}$	*n*	Electrolyte	Ref.
Nanoporous Ag	0.991 V_{RHE}	0.880 V_{RHE}	4	0.1 M KOH	[S1]
AgCl NWs	1.012 V_{RHE}	0.84 V_{RHE}	3.84	0.1 M NaOH	[S2]
Nanoporous Ag	1.014 V_{RHE}	0.874 V_{RHE}	4.0	0.1 M KOH	[S3]
Ag nanodendrites	0.98 V_{RHE}	0.76 V_{RHE}	3.9	0.1 M KOH	[S4]
Ag-MnO_x/G	0.90 V_{RHE}	0.72 V_{RHE}	4.0	0.1 M KOH	[S5]
CuAg@Ag/NGS	0.94 V_{RHE}	0.85 V_{RHE}	3.6-3.8	0.1 M KOH	[S6]
Ag NW/C	0.904 V_{RHE}	0.801 V_{RHE}	4	0.1 M NaOH	[S7]
Ag NWs@NG	-0.05 V_{AgCl}	-0.14 V_{AgCl}	4	0.1 M KOH	[S8]
NCNTs-AgNFs	-0.1 V_{AgCl}	-0.272 V_{AgCl}	3.85	0.1 M KOH	[S9]
C-N/Ag-900-K	0.93 V_{RHE}	0.71 V_{RHE}	4.0	0.1 M KOH	[S10]
Ag-CeO_2	0.905 V_{RHE}	0.717 V_{RHE}	3.46	0.1 M KOH	[S11]
Ag-$Pr_{0.95}Ba_{0.95}Mn_2O_{5+\delta}$/C	0.92 V_{RHE}	0.81 V_{RHE}	4	0.1 M KOH	[S12]
HCT@HPC@Ag NPs	0.904 V_{RHE}	0.754 V_{RHE}	3.6-3.9	0.1 M KOH	[S13]
AgNCs/NG	-0.1 V_{AgCl}	-0.25 V_{AgCl}	3.55	0.1 M KOH	[S14]
Silver nanonet/graphene nanohybrid	0.924 V_{RHE}	0.674 V_{RHE}	4	0.1 M KOH	[S15]
rGO/MnO_2/Ag	0.9 V_{RHE}	0.732 V_{RHE}	3.90	0.1 M KOH	[S16]
Ag-GNR	-0.133 V_{AgCl}	-0.352 V_{AgCl}	3.51	0.1 M KOH	[S17]
Ag/GO/C	0.826 V_{RHE}	0.696 V_{RHE}	/	0.1 M NaOH	[S18]
Porous PLD-Ag	1.007 V_{RHE}	0.863 V_{RHE}	3.9-4.0	0.1 M KOH	This Work

References:

S1. Zhao, W.; Huang, K.; Zhang, Q. H.; Wu, H.; Gu, L.; Yao, K. F.; Shen, Y.; Shao, Y., In-situ synthesis, operation and regeneration of nanoporous silver with high performance toward oxygen reduction reaction. Nano Energy 2019, 58, 69-77.

S2. Kim, S. J.; Lee, S. C.; Lee, C.; Kim, M. H.; Lee, Y., Evolution of silver to a better electrocatalyst: Water-assisted oxygen reduction reaction at silver chloride nanowires in alkaline solution. Nano Energy 2018, 48, 134-143.

S3. Xie, X.; Wei, M.; Du, L.; Nie, Y.; Qi, X.; Shao, Y.; Wei, Z., Enhancement in kinetics of the oxygen reduction on a silver catalyst by introduction of interlaces and defect-rich facets. Journal of Materials Chemistry A 2017, 5 (29), 15390-15394.

S4. Chen, Z. Y.; Li, C. L.; Ni, Y. Y.; Kong, F. T.; Zhang, Y. B.; Kong, A. G.; Shan, Y. K., TCNQ-induced in-situ electrochemical deposition for the synthesis of silver nanodendrites as efficient bifunctional electrocatalysts. Electrochim. Acta 2017, 239, 45-55.

S5. Shypunov, I.; Kongi, N.; Kozlova, J.; Matisen, L.; Ritslaid, P.; Sammelselg, V.; Tammeveski, K., Enhanced Oxygen Reduction Reaction Activity with Electrodeposited Ag on Manganese Oxide-Graphene Supported Electrocatalyst. Electrocatalysis 2015, 6 (5), 465-471.

S6. Tran Duy, T.; Nguyen Dinh, C.; Hoa Van, H.; Kim, N. H.; Lee, J. H., CuAg@Ag Core-Shell Nanostructure Encapsulated by N-Doped Graphene as a High-Performance Catalyst for Oxygen Reduction Reaction. ACS Applied Materials & Interfaces 2018, 10 (5), 4672-4681.

S7. Kim, S.-M.; Lee, S.-Y., The plasma-induced formation of silver nanocrystals in aqueous solution and their catalytic activity for oxygen reduction. Nanotechnology 2018, 29 (8).

S8. Ji, D.; Wang, Y.; Chen, S.; Zhang, Y.; Li, L.; Ding, W.; Wei, Z., Nitrogen-doped graphene wrapped around silver nanowires for enhanced catalysis in oxygen reduction reaction. Journal of Solid State Electrochemistry 2018, 22 (7), 2287-2296.

S9. Yasmin, S.; Ahmed, M. S.; Jeon, S., A noble silver nanoflower on nitrogen doped carbon nanotube for enhanced oxygen reduction reaction. International Journal of Hydrogen Energy 2017, 42 (2), 1075-1084.

S10. Zhang, Z.; Li, H.; Hu, J.; Liu, B.; Zhang, Q.; Fernandez, C.; Peng, Q., High oxygen reduction reaction activity of C-N/Ag hybrid composites for Zn-air battery. Journal of Alloys and Compounds 2017, 694, 419-428.

S11. Sun, S.; Xue, Y.; Wang, Q.; Li, S.; Huang, H.; Miao, H.; Liu, Z., Electrocatalytic activity of silver decorated ceria microspheres for the oxygen reduction reaction and their application in aluminium-air batteries. Chem. Commun. 2017, 53 (56), 7921-7924.

S12. Zhang, Y.-Q.; Tao, H.-B.; Liu, J.; Sun, Y.-F.; Chen, J.; Hua, B.; Thundat, T.; Luo, J.-L., A rational design for enhanced oxygen reduction: Strongly coupled silver nanoparticles and engineered perovskite nanofibers. Nano Energy 2017, 38, 392-400.

S13. Cao, C.; Wei, L.; Su, M.; Wang, G.; Shen, J., Template-free and one-pot synthesis of N-doped hollow carbon tube @ hierarchically porous carbon supporting homogeneous AgNPs for robust oxygen reduction catalyst. Carbon 2017, 112, 27-36.

S14. Jin, S., Chen, M., Dong, H., He, B., Lu, H., Su, L., Dai, W., Zhang, Q., Zhang, X., Stable silver nanoclusters electrochemically deposited on nitrogen-doped graphene as efficient electrocatalyst for oxygen reduction reaction. Journal of Power Sources 2015, 274, 1173-1179.

S15. Liu, R.; Yu, X.; Zhang, G.; Zhang, S.; Cao, H.; Dolbecq, A.; Mialane, P., Keita, B., Zhi, L., Polyoxometalate-mediated green synthesis of a 2D silver nanonet/graphene nanohybrid as

a synergistic catalyst for the oxygen reduction reaction. Journal of Materials Chemistry A 2013, 1 (38), 11961-11969.
S16. Lee, K., Ahmed, M. S., Jeon, S., Electrochemical deposition of silver on manganese dioxide coated reduced graphene oxide for enhanced oxygen reduction reaction. Journal of Power Sources 2015, 288, 261-269.
S17. Davis, D. J., Raji, A.-R. O., Lambert, T. N., Vigil, J. A., Li, L., Nan, K., Tour, J. M., Silver-Graphene Nanoribbon Composite Catalyst for the Oxygen Reduction Reaction in Alkaline Electrolyte. Electroanalysis 2014, 26 (1), 164-170.
S18. Yuan, L.; Jiang, L.; Liu, J., Xia, Z., Wang, S.; Sun, G., Facile synthesis of silver nanoparticles supported on three dimensional graphene oxide/carbon black composite and its application for oxygen reduction reaction. Electrochim. Acta 2014, 135, 168-174.