Rare-earth oxides promoted Pd electrocatalyst for formic acid oxidation

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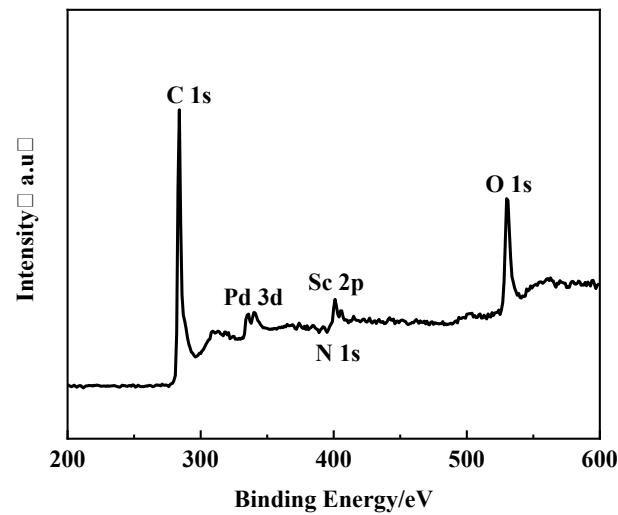
Figure S1. XPS survey spectrum of the Pd-Sc$_2$O$_3$/N-rGO-2/3.
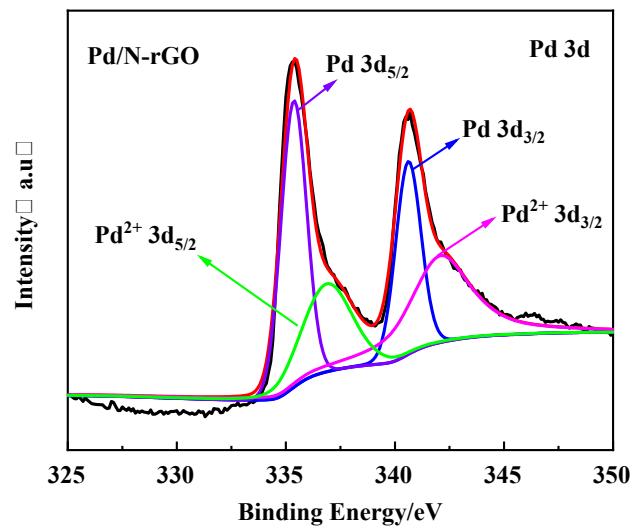
Figure S2. XPS spectrum of Pd 3d for Pd/N-rGO.
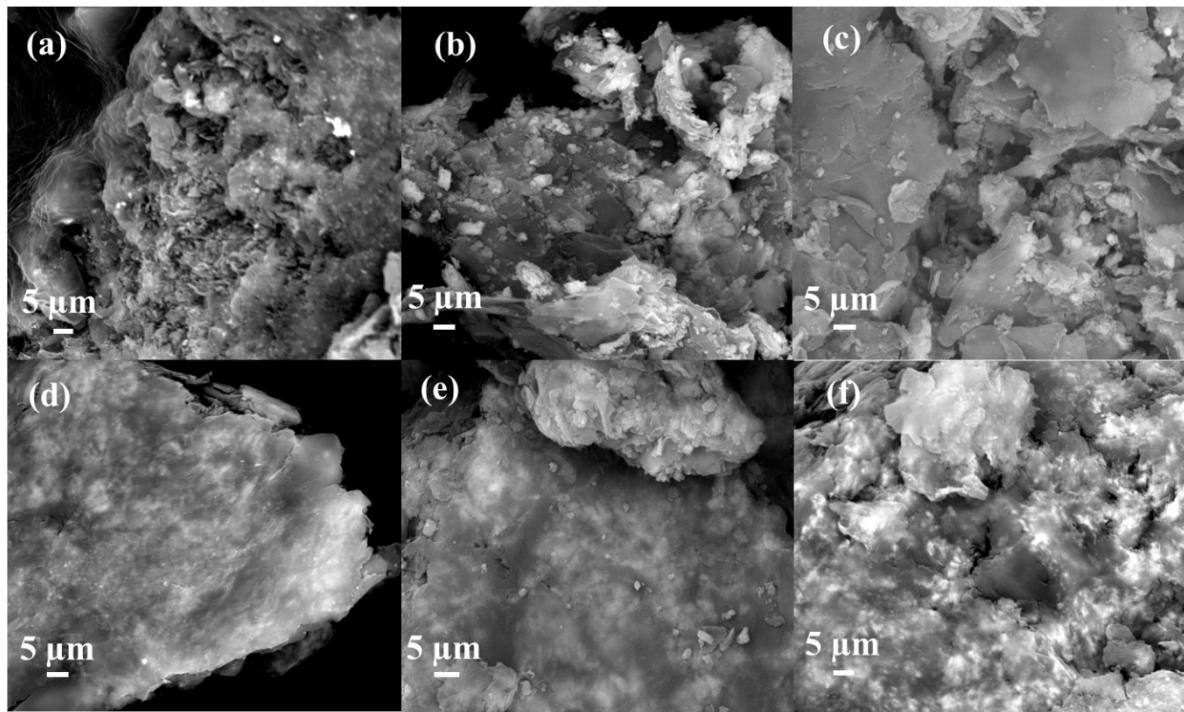
Figure S3. SEM images of (a) Pd/N-rGO and (b-f) Pd-Sc$_2$O$_3$/N-rGO-x. SEM images of (b) Pd-Sc$_2$O$_3$/N-rGO-1/3, (c) Pd-Sc$_2$O$_3$/N-rGO-1/2, (d) Pd-Sc$_2$O$_3$/N-rGO-2/3, (e) Pd-Sc$_2$O$_3$/N-rGO-1, (f) Pd-Sc$_2$O$_3$/N-rGO-3/2.
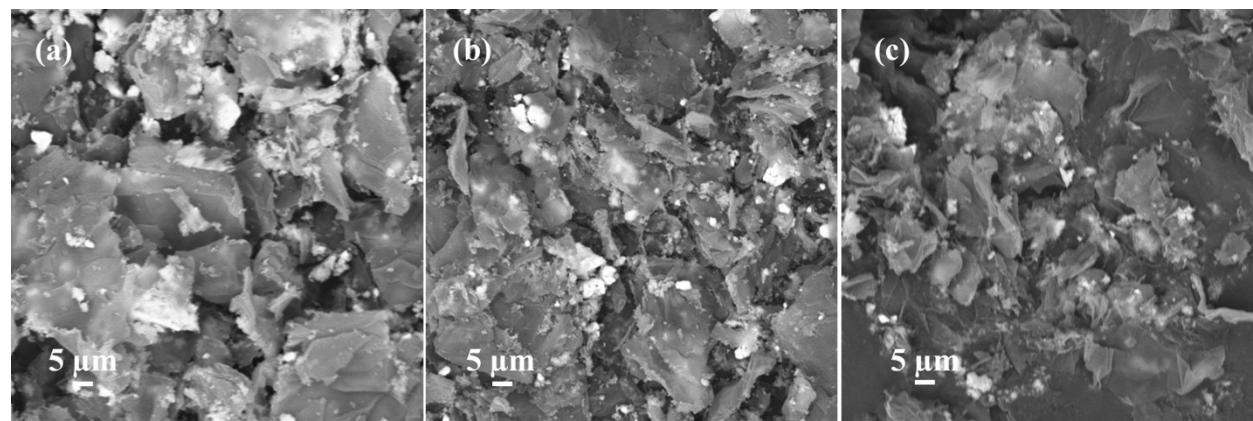
Figure S4. SEM images of (a) Pd-CeO$_2$/N-rGO, (b) Pd-La$_2$O$_3$/N-rGO, (c) Pd-Pr$_2$O$_3$/N-rGO.
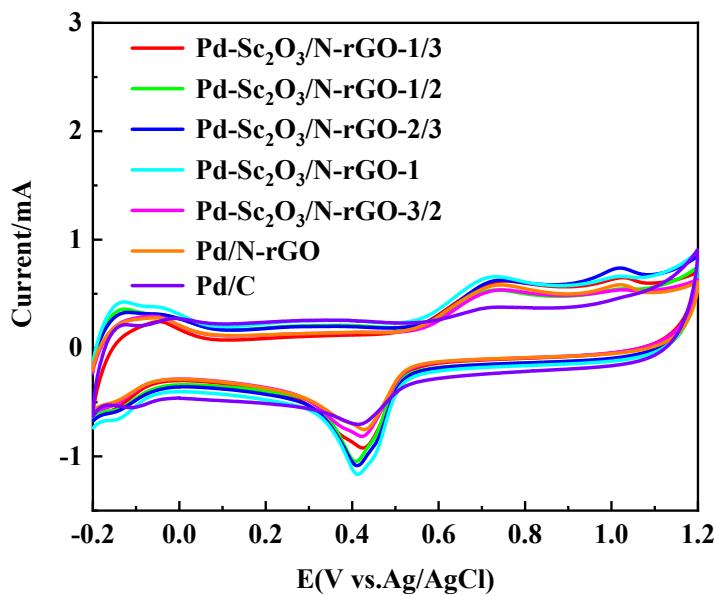
Figure S5. CV curves of Pd/C, Pd/N-rGO and Pd-Sc$_2$O$_3$/N-rGO-x in 0.5 M H$_2$SO$_4$ solution.

Supplementary Note 1

The electrochemically surface area (ECSA) is calculated from charges involved in the reduction of Pd oxide processes during the negative scan, according to the equation of ECSA$_{PdO}$ = Q/(C * Pd$_m$) in the potential range of 0.3-0.6 V, where Q is the integral of the peak from the reduction of Pd oxide, Pd$_m$ is the load of Pd on the electrode, and C is the double-layer capacitance of 0.424 mC cm^{-2} (Ref: Electrochim. Acta, 2019, 324, 134816). Based on the CVs, the ECSA$_{PdO}$ of Pd-Sc$_2$O$_3$/N-rGO-2/3 is found to be 5.63 m^2 g^{-1}, Pd-Sc$_2$O$_3$/N-rGO-1/3 (4.59 m^2 g^{-1}), Pd-Sc$_2$O$_3$/N-rGO-1/2 (4.60 m^2 g^{-1}), Pd-Sc$_2$O$_3$/N-rGO-1 (5.61 m^2 g^{-1}), Pd-Sc$_2$O$_3$/N-rGO-3/2 (4.45 m^2 g^{-1}), Pd/N-rGO (4.09 m^2 g^{-1}) and Pd/C (3.52 m^2 g^{-1}).
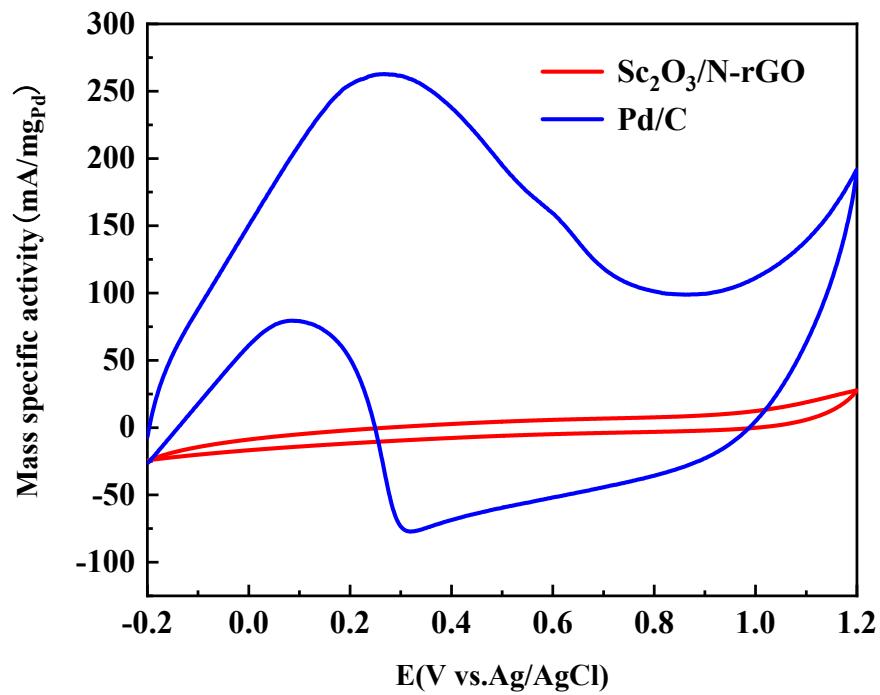
Figure S6 CV curves for Sc_2O_3/N-rGO and Pd/C catalyst in 0.5 M H_2SO_4 + 1.0 M HCOOH solutions.
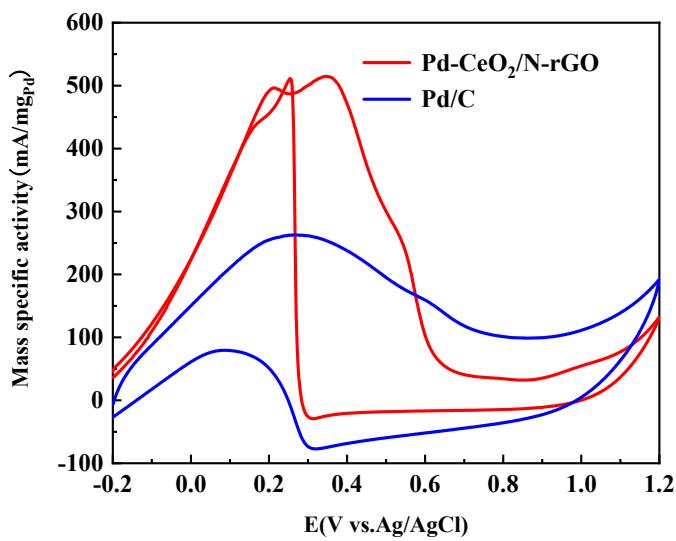
Figure S7 CV curves for Pd-CeO$_2$/N-rGO and Pd/C catalyst in 0.5 M H$_2$SO$_4$ + 1.0 M HCOOH solutions.
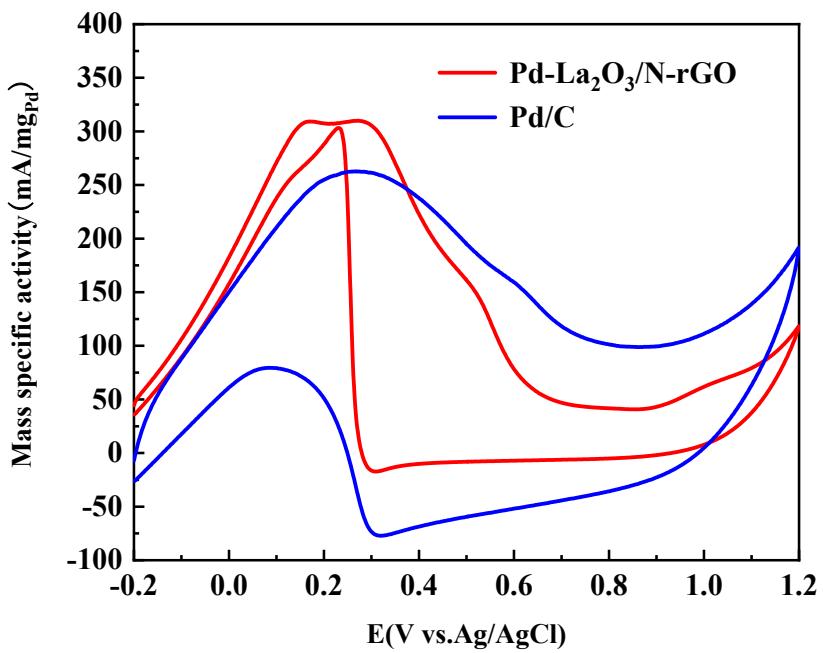
Figure S8 CV curves for Pd-La$_2$O$_3$/N-rGO and Pd/C catalyst in 0.5 M H$_2$SO$_4$ + 1.0 M HCOOH solutions.
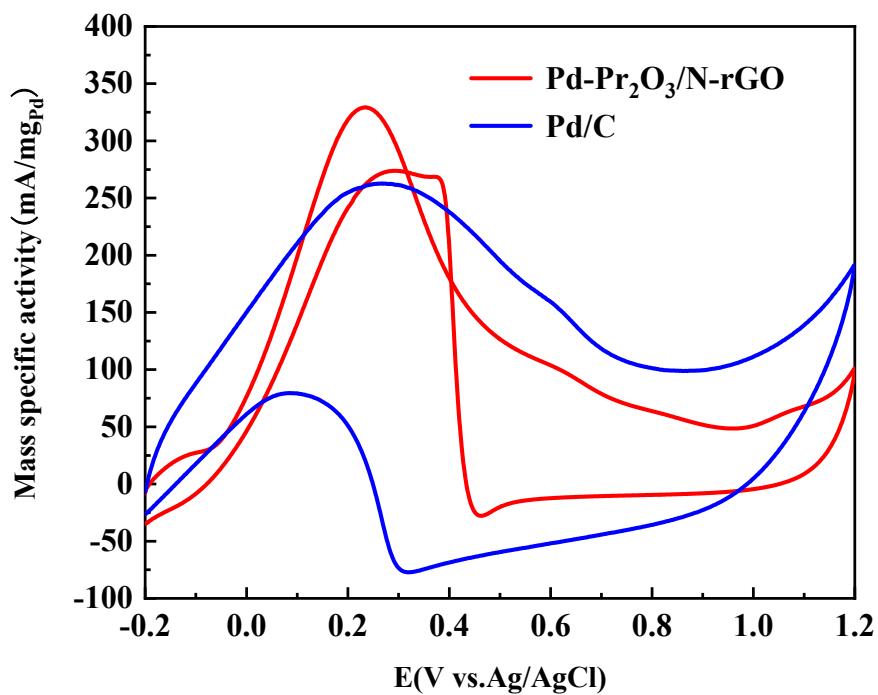
Figure S9 CV curves for Pd-Pr$_2$O$_3$/N-rGO and Pd/C catalyst in 0.5 M H$_2$SO$_4$ + 1.0 M HCOOH solutions.
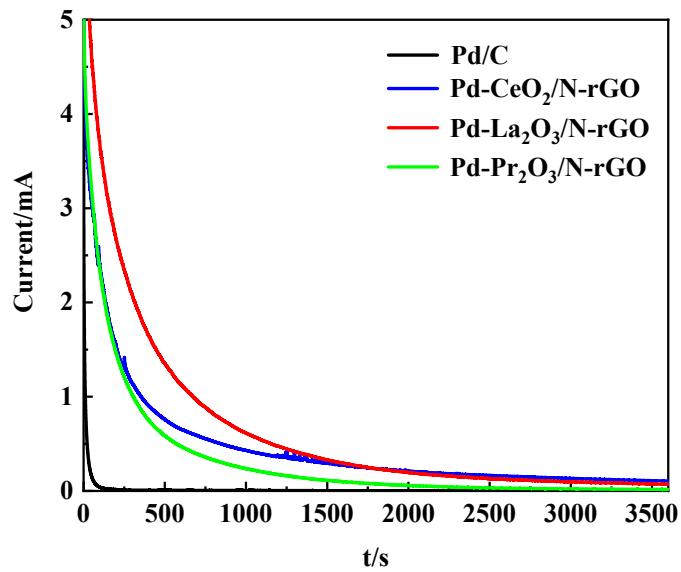
Figure S10 Chronoamperometric curves of Pd-CeO$_2$/N-rGO, Pd-La$_2$O$_3$/N-rGO, Pd-Pr$_2$O$_3$/N-rGO and Pd/C in 0.5 M H$_2$SO$_4$ + 1 M HCOOH solution.

Table S1. ICP-OES results of Pd-Sc$_2$O$_3$/N-rGO-x, Pd/N-rGO, Pd-CeO$_2$/N-rGO, Pd-La$_2$O$_3$/N-rGO and Pd-Pr$_2$O$_3$/N-rGO catalysts.

Samples	Pd (wt.%)
Pd-Sc$_2$O$_3$/N-rGO-1/3	8.89
Pd-Sc$_2$O$_3$/N-rGO-1/2	9.35
Pd-Sc$_2$O$_3$/N-rGO-2/3	8.27
Pd-Sc$_2$O$_3$/N-rGO-1	8.65
Pd-Sc$_2$O$_3$/N-rGO-3/2	9.13
Pd/N-rGO	9.08
Pd-CeO$_2$/N-rGO	9.47
Pd-La$_2$O$_3$/N-rGO	8.46
Pd-Pr$_2$O$_3$/N-rGO	8.30

Table S2. Binding energies and their shifts of Pd 3d for Pd/N-rGO and Pd-Sc$_2$O$_3$/N-rGO-2/3 catalysts.

Catalyst	Species	Binding Energy (eV)
Pd/N-rGO	Pd(0) 3d$_{3/2}$	340.6
	Pd(0) 3d$_{5/2}$	335.4
Pd-Sc$_2$O$_3$/N-rGO-2/3	Pd(0) 3d$_{3/2}$	340.3
	Pd(0) 3d$_{5/2}$	335.1

Table S3. Comparison of electrochemical performance of reported literature and the current work

Samples	[a]E_f (V)	[b]E_r (V)	[c]J (A/m^2)	[d]J (A/m^2)	[e]I_f/I_b	Ref.
Pd$_{30}$La$_{70}$/rGO	0.66	0.56	694.5	627	1.11	1
Pd-CeO$_2$/C	0.13	0.15	350	300	1.16	2
Pd$_4$Sm$_6$/rGO	0.30	0.20	968	589	1.6	3
PdEuO$_x$/C	0.33	0.35	700	650	1.06	4
Pd$_6$Y$_4$/rGO	0.36	0.46	1066	1329.5	0.80	5
Pd/C	0.28	0.12	146	43	3.3	This work
Pd/N-rGO	0.05	0.1	162	99.5	1.62	This work
Pd-Sc$_2$O$_3$/N-rGO-2/3	0.36	0.43	449	546	0.82	This work

[a] E_f = forward peak potential.
[b] E_r = backward peak potential.
[c] J = forward current density.
[d] J = backward current density.
[e] I_f/I_b = ratio of forward to backward oxidation peak.

References

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