**Electronic Supplementary Information** 

# Self-sacrificed two-dimensional REO(CH<sub>3</sub>COO) template assisted synthesis of ultrathin rare earth oxide nanoplates

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#### Materials

Oleic acid (OA; >90%, TCI), oleylamine (OAm; >98%), cerium acetate hydrate (Ce(CH<sub>3</sub>COO)<sub>3</sub> nH<sub>2</sub>O, AR, J&K), ascorbic acid (AR, Beijing Chemical Works), acetic acid (HAc, 99%, AR, Acros), ethanol (AR, Beijing Chemical Works), and cyclohexane (AR, Beijing Chemical Works) are used as received without any further purification.

# Preparation of RE(CH<sub>3</sub>COO)<sub>3</sub> nH<sub>2</sub>O

In a typical synthesis, 20 mmol La<sub>2</sub>O<sub>3</sub> is added into a solution containing about 9.0 g  $H_2O$  and 150 mmol acetic acid. The resultant slurry is heated under refluxing and magnetic stirring until an optical transparent solution is formed. The solution is filtered to remove insoluble impurities (if any), and then carefully concentrated under heating until the lanthanum acetate crystallizes into powders. The powders are then dried at 140 °C overnight. All the other RE(CH<sub>3</sub>COO)<sub>3</sub> nH<sub>2</sub>O (except for Ce) were prepared following similar procedures.

# Preparation of CeO(CH<sub>3</sub>COO) ML nanoplates

In a typical synthesis, 2 mmol Ce(CH<sub>3</sub>COO)<sub>3</sub> nH<sub>2</sub>O and 1 mmol ascorbic acid are added into a mixture of 3 mmol OA and 9 mmol OAm (solution B) in a three-necked flask (100 mL) at room temperature. The resulting slurry is heated to 120 °C with vigorous stirring under vacuum. At 15 minutes after the solution reaches 120 °C, the solution is quickly extracted with a 10 mL syringe and then injected into another three-necked flask with a solution of 6 mmol OA and 18 mmol OAm (solution A) under 310 °C and N<sub>2</sub> atmosphere. At 30 minutes after the injection, stop heating and cool the solution down to about 80 °C under N<sub>2</sub> atmosphere. The products are flocculated by adding 40 mL ethanol into the reaction mixture and centrifugated under 7800 rpm for 10 min. The products are collected and washed with ethanol (40 mL) and cyclohexane (5 mL) for another 2 times.

#### **Preparation of ceria SL nanoplates**

In a typical synthesis, 2 mmol Ce(CH<sub>3</sub>COO)<sub>3</sub> nH<sub>2</sub>O and 1 mmol ascorbic acid are added into a mixture of 3 mmol OA and 9 mmol OAm (solution B) in a three-necked flask (100 mL) at room temperature. The resulting slurry is heated to 120 °C with vigorous stirring under vacuum. At 15 minutes after the solution reaches 120 °C, the solution is quickly extracted with a 10 mL syringe and then injected into another three-necked flask with a solution of 6 mmol OA and 18 mmol OAm (solution A) under 310 °C and N<sub>2</sub> atmosphere. At 3 minutes after the injection, inject a mixture of 3 mmol OA and 9 mmol OAm into the reaction system. 30 min later, stop heating and cool the solution down to about 80 °C under N<sub>2</sub> atmosphere. The products are flocculated by adding 40 mL ethanol into the reaction mixture and centrifugated under 7800 rpm for 10 min. The products are collected and washed with ethanol (40 mL) and cyclohexane (5 mL) for another 2 times. The synthesis can also be done as follows: 2 mmol Ce(CH<sub>3</sub>COO)<sub>3</sub> nH<sub>2</sub>O and 1 mmol ascorbic acid are directly added into a mixture of 5 mmol OA and 15 mmol OAm (solution B) in a three-necked flask (100 mL) at room temperature. The resulting slurry is heated to 120  $^{\circ}$ C with vigorous stirring under vacuum. At 15 minutes after the solution reaches 120  $^{\circ}$ C, the solution is quickly extracted with a 10 mL syringe and then injected into another three-necked flask with a solution of 6 mmol OA and 18 mmol OAm (solution A) under 310  $^{\circ}$ C and N<sub>2</sub> atmosphere. At 30 minutes after injection, the solution is cooled down to about 80  $^{\circ}$ C under N<sub>2</sub> atmosphere and the products are flocculated by adding 40 mL ethanol into the reaction mixture and centrifugated under 7800 rpm for 10 minutes. The product is collected and washed with ethanol (40 mL) and cyclohexane (5 mL) for another 2 times.

#### **Preparation of ceria ML nanoplates**

In a typical synthesis, 2 mmol Ce(CH<sub>3</sub>COO)<sub>3</sub> nH<sub>2</sub>O and 1 mmol ascorbic acid are added into a mixture of 3 mmol OA and 9 mmol OAm (solution B) in a three-necked flask (100 mL) at room temperature. The resulting slurry is heated to 120 °C with vigorous stirring under vacuum. At 15 minutes after the solution reaches 120 °C, the solution is quickly extracted with a 10 mL syringe and then injected into another three-necked flask with a solution of 6 mmol OA and 18 mmol OAm (solution A) under 310 °C and N<sub>2</sub> atmosphere. At 20 minutes after the injection, raising the reaction temperature to 380 °C (**High temperature, caution!**). 30 min later, stop heating and cool the solution down to about 80 °C under N<sub>2</sub> atmosphere. The products are flocculated by adding 40 mL ethanol into the reaction mixture and centrifugated under 7800 rpm for 10 min. The products are collected and washed with ethanol (40 mL) and cyclohexane (5 mL) for another 2 times.

The synthesis can also be done as follows: 2 mmol Ce(CH<sub>3</sub>COO)<sub>3</sub> nH<sub>2</sub>O and 1 mmol ascorbic acid are added into a mixture of 3 mmol OA and 9 mmol OAm (solution B) in a three-necked flask (100 mL) at room temperature. The resulting slurry is heated to 120  $^{\circ}$ C with vigorous stirring under vacuum. At 15 minutes after the solution reaches 120  $^{\circ}$ C, the solution is quickly extracted with a 10 mL syringe and then directly injected into another three-necked flask with a solution of 6 mmol OA and 18 mmol OAm (solution A) under 380  $^{\circ}$ C (High temperature, caution!) and N<sub>2</sub> atmosphere. At 30 minutes after the injection, the solution slowly turns from red brown to greenish yellow. The solution is then cooled down to about 80  $^{\circ}$ C under N<sub>2</sub> atmosphere and the products are flocculated by adding 40 mL ethanol into the reaction mixture and centrifugated under 7800 rpm for 10 minutes. The product is collected and washed with ethanol (40 mL) and cyclohexane (5 mL) for another 2 times.

# Preparation of REO(CH<sub>3</sub>COO) ML nanoplates

From LaO(CH<sub>3</sub>COO) to TbO(CH<sub>3</sub>COO), the synthesis method is same to that of CeO(CH<sub>3</sub>COO) ML nanoplates, only without AA used.

For DyO(CH<sub>3</sub>COO) to LuO(CH<sub>3</sub>COO) and YO(CH<sub>3</sub>COO), the synthesis process need minor adjustment. In a typical synthesis, 2 mmol Dy(CH<sub>3</sub>COO)<sub>3</sub>  $nH_2O$  is added into a

mixture of 8 mmol HAc and 8 mmol OAm in a three-necked flask (100mL) at room temperature. The resulting slurry is heated to 120 °C with vigorous stirring under vacuum. At 15 minutes after the solution reaches 120 °C, the solution is quickly extracted with a 10 mL syringe and then injected into another three-necked flask with a solution of 20 mmol OAm under 340 °C and N<sub>2</sub> atmosphere. At 30 minutes after the injection, the solution is cooled down to about 80 °C under N2 atmosphere and the products are flocculated by adding 40 mL ethanol into the reaction mixture and centrifugated under 7800 rpm for 10 min. The product is collected and washed with ethanol (40 mL) and cyclohexane (5 mL) for another 2 times.

# Preparation of RE<sub>2</sub>O<sub>3</sub> SL nanoplates

The synthetic procedures for  $RE_2O_3$  SL-nanoplates are same to that of ceria SL nanoplates, only without AA added.

# Characterization

Transmission electron microscopy (TEM) images, high resolution TEM (HRTEM) images, and selected area electron diffraction (SAED) patterns were taken on a FEG-TEM (JEM-2100F, JEOL, Japan) operated at 200 kV. The powder X-ray diffraction (XRD) patterns of the as-synthesized products were obtained on a Rigaku D/MAX-2000 diffractometer (Japan) with a slit of  $1/2^{\circ}$  at a 2 $\theta$  scan rate of 3 ° min<sup>-1</sup> under Cu K $\alpha$  radiation ( $\lambda$ = 1.5406 Å). The small angle X-ray diffraction (SAXRD) patterns were obtained on the same diffractometer with a slit of  $1/6^{\circ}$  at a 2 $\theta$  scan rate of 1 ° min<sup>-1</sup>. TG-DSC curve was measured on TA Instruments, SDT Q600 TGA/DSC.



**Fig. S1**. Crystal structure of typical  $Ln_2O_2CO_3$  and LnOX (X = Cl, Br, I),  $La_2O_2CO_3$ -II a), PrOCl b), yellow balls represent lanthanide ions, red balls represent oxygen ions, blue balls represent carbonate ions and green balls represent chloride ions.<sup>S1</sup>



Fig. S2. HRTEM image of the as-synthesized CeO(CH<sub>3</sub>COO) ML nanoplates.



**Fig. S3**. XRD patterns of the products obtained at different time after injection at 310  $^{\circ}$ C. The broad peak at around 20°, indicated by \*, is due to the diffraction of the sample holder.



**Fig. S4**. FT-IR a) and SAXRD b) pattern of the as-synthesized ceria SL nanoplates. Peaks A, B, C, D in a) represent the C-H stretching vibration in (-HC=CH-), C-H stretching vibration (asymmetric and symmetric) in (-CH<sub>2</sub>-), C-O stretching vibration (asymmetric and symmetric) in (-COO<sup>-</sup>) and CH<sub>2</sub> in-plane deformations rocking in  $[-(CH_2)_n-]$  (n  $\geq 6$ ). Inset in b) is the schematic illustration of the stacking pattern of the OA-capped SL nanoplates in the SAXRD test.



Fig. S5. XRD pattern of the as-synthesized ceria SL nanoplates



**Fig. S6**. TEM image a), XRD pattern b) and FT-IR pattern c) of the as-synthesized Ce<sub>2</sub>O<sub>2</sub>CO<sub>3</sub> ML nanoplates, the XRD pattern in b) can match well with the XRD pattern of Ce<sub>2</sub>O<sub>2</sub>CO<sub>3</sub> synthesized at 350 °C reported in reference S2a, there is no standard XRD card of Ce<sub>2</sub>O<sub>2</sub>CO<sub>3</sub> reported to date, the reference pattern in b) is the pattern of Pr<sub>2</sub>O<sub>2</sub>CO<sub>3</sub> I coming from reference S2b. The vibration peaks noted by the arrows in c) are due to the v<sub>2</sub> and v<sub>3</sub> vibration of the carbonate ions which confirm the existence of carbonates ions in the intermediate. <sup>S2c,S2d</sup>



**Fig. S7**. TEM images a), b), c) and digital photo d) of the as-synthesized ceria ML-nanoplates, the scale bar is 20 nm for a) and b), and 5 nm for c).



Fig. S8. XRD pattern of the as-synthesized ceria ML nanoplates.



**Fig. S9.** TEM images of  $LnO(CH_3COO)$ .  $LaO(CH_3COO)$  a);  $PrO(CH_3COO)$  b);  $NdO(CH_3COO)$  c);  $SmO(CH_3COO)$  d);  $EuO(CH_3COO)$  e);  $GdO(CH_3COO)$  f);  $TbO(CH_3COO)$  g);  $DyO(CH_3COO)$  h);  $HoO(CH_3COO)$  i);  $ErO(CH_3COO)$  j);  $TmO(CH_3COO)$  k);  $YbO(CH_3COO)$  l);  $LuO(CH_3COO)$  m);  $YO(CH_3COO)$  n).



Fig. S10. XRD patterns of the as-synthesized  $LnO(CH_3COO)$ , the reference pattern is the XRD pattern of  $LaO(CH_3COO)$  produced from reference S3.



**Fig. S11**. TEM images of lanthanide oxide nanoplates and nanodisks. La<sub>2</sub>O<sub>3</sub> a);  $Pr_2O_3$  b);  $Nd_2O_3$  c);  $Sm_2O_3$  d);  $Eu_2O_3$  e);  $Gd_2O_3$  f);  $Tb_2O_3$  g);  $Dy_2O_3$  h);  $Ho_2O_3$  i);  $Er_2O_3$  j);  $Tm_2O_3$  k);  $Yb_2O_3$  l);  $Lu_2O_3$  m);  $Y_2O_3$  n).



Fig. S12. XRD patterns of lanthanide oxide nanoplates and nanodisks.



**Fig. S13**. HRTEM images of the as-synthesized SL  $Eu_2O_3$  a),  $Gd_2O_3$  b) and  $Y_2O_3$  c) nanoplates, the insets in a), b) and c) are the FFT patterns of the selected area in a), b) and c).

# References

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