Electronic Supplementary Material (ESI) for Journal of Materials Chemistry
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Supporting Information

Remarkable Optical and Magnetic Properties of Ultra-thin Europium Oxysulfide Nanorods

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Experimental Section

Synthesis of $Eu_{2+x}O_2S$ nanorods

All chemicals used in this experiment were used without further purification. The sodium oleate (95%) was acquired from TCI America, while the other chemicals (europium (III) chloride hexahydrate (99.99%), oleylamine (70%), n-hexane, acetone, isopropanol, diethylammonium diethyldithiocarbamate (98%), 1-dodecanethiol (98%), and phenanthroline (99%)) were purchased from Sigma-Aldrich. The syringe pump was purchased from Razel Scientific Instruments. Prior to the synthesis of the nanorods, europium oleate was synthesized using the europium (III) chloride hexahydrate, the sodium oleate, ethanol, hexane, and deionized water via a previously reported procedure [25]. Eight mmol of europium (III) chloride hexahydrate and 24 mmol of sodium oleate were combined along with 16 mL of ethanol, 12 mL of deionized water, and 28 mL of hexane in a three-mouth flask. The substance was heated to 60°C and left for about three hours. Afterwards, a seperatory funnel was used to segregate the europium oleate in a

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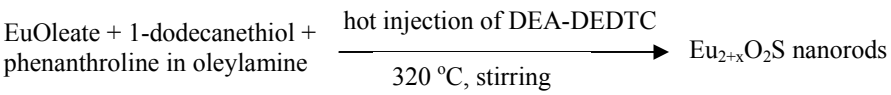
layer of hexane from the unnecessary products. Deionized water was added to the substance and after waiting several minutes, the bottom layer was drained again. This was repeated four times to clean the resulting substance.

The nanorods themselves were synthesized in a Schlenk line. To synthesize europium oxysulfide nanorods with a diameter of 3.2 nm and an aspect ratio of 5, a mixture of 0.2 mmol of europium oleate, 0.2 mmol of phenanthroline, 0.1 mL of dodecanethiol, and 10 mL of oleylamine was vacuumed and heated to 80 °C in a three-neck flask, after which the mixture was left for 40 minutes to allow the mixture to purify prior to increasing the temperature to 320 °C, all while being constantly stirred. Meanwhile, 0.2 mml of diethylammonium diethyldithiocarbamate (DEA-DEDTC) was mixed with 5 mL of oleylamine and degased with argon. Once the desired temperature of 320 °C was reached, the syringe pump was used to inject the previously de-gassed mixture of DEDTC and oleylamine into the heated flask at the desired rate (5 mL/min). The substance reacted for an hour before being inserted into a vial, using acetone as a solvent. After several hours passed to allow the nanorods to precipitate, the liquid was poured out of the vial slowly before being refilled with acetone. This process was repeated four times in order to clean the samples.

To change the size and aspect ratio of the nanorods, the injection rate was varied from 0.5 mL/min to 25 mL/min, and the amount of phenanthroline used was adjusted, ranging from no phenanthroline present to up to 0.4 mmol.

Scheme S1. Reaction schematic of the synthesis of $Eu_{2+x}O_2S$ nanorods



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Characterization

High resolution transmission electron microscopy (HR-TEM) images were obtained using a Philips CM 200 TEM operating at 200 kV. X-ray diffraction measurements (XRD) were obtained using a Scintag X1 powder diffractometer. Energy dispersive x-ray (EDS) analysis was performed on the samples using a Hitachi S-4200 Scanning Electron Microscope. Fourier transform infrared spectroscopy (FTIR) measurements were obtained using a Bruker Tensor 27 Fourier Transform Infrared spectrometer. Atomic force microscopy measurements (AFM) were obtained using a Digital Instruments Nanoscan III Atomic Force Microscope.

Table S1. The diameters and aspect ratios of $Eu_{2+x}O_2S$ nanorods synthesized with different injection rates with the amount of phenanthroline fixed at 0.2 mmol.

injection rate (mL/min)	0.5	5	10	25
diameter (nm)	3.5	3.2	3	1.5
aspect ratio	5	5	5	5

Table S2. The diameters and aspect ratios of $Eu_{2+x}O_2S$ nanorods synthesized with different amounts of phenanthroline with the inject rate fixed at 5 mL/min.

phenanthroline (mmol)	0 (Eu_2O_3)	0.1	0.2	0.4
diameter (nm)	1.5	3.5	3.2	1.0
aspect ratio	10	4	5	20

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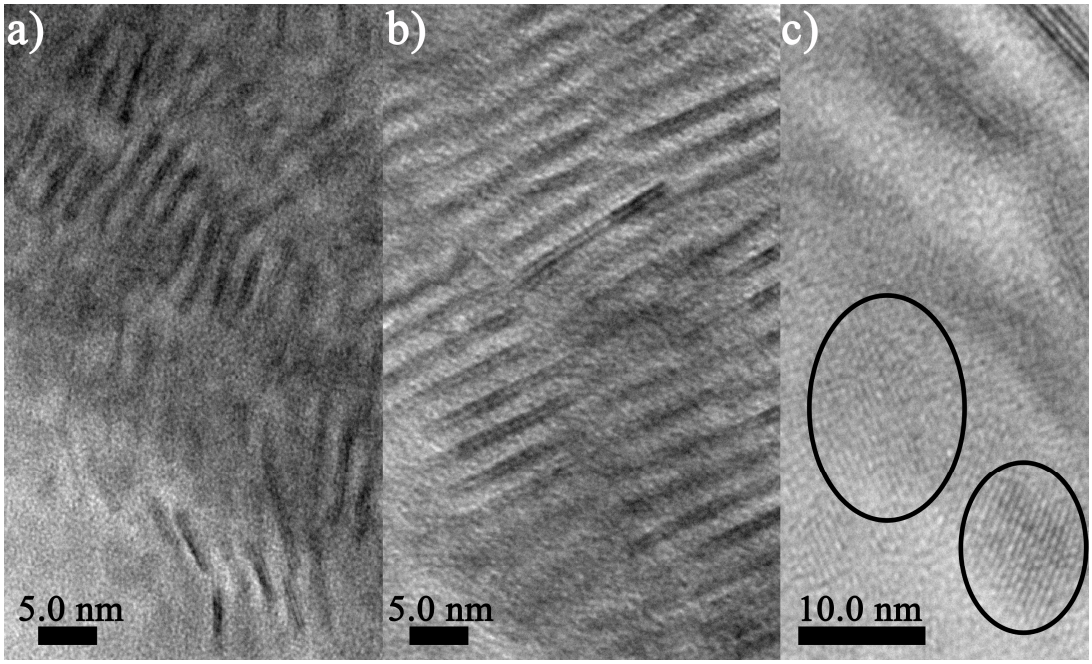

Figure S1. a) TEM image of $Eu_{2+x}O_2S$ NRs with a diameter of 1.5 nm and an aspect ratio of 5. b) TEM image of Eu_2O_3 NRs with a diameter of 1.5 nm and an aspect ratio of 10. c) TEM image of 2D $Eu_{2+x}O_2S$ nanoplates approximately 8.0 nm in width.

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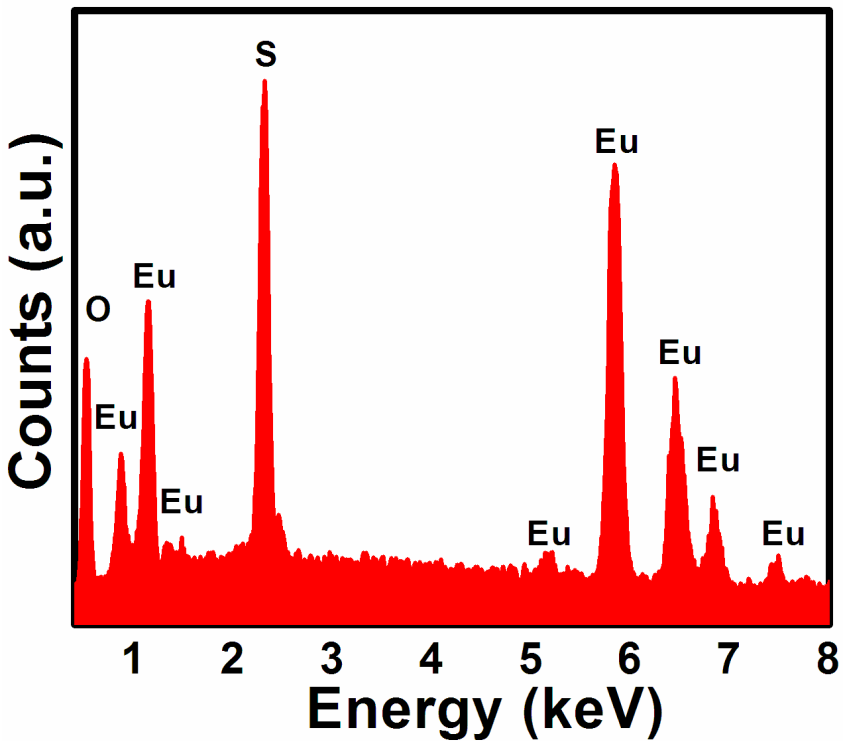

Figure S2. EDS of $Eu_{2+x}O_2S$ nanorods with a diameter of 3.2 nm and an aspect ratio of 5.

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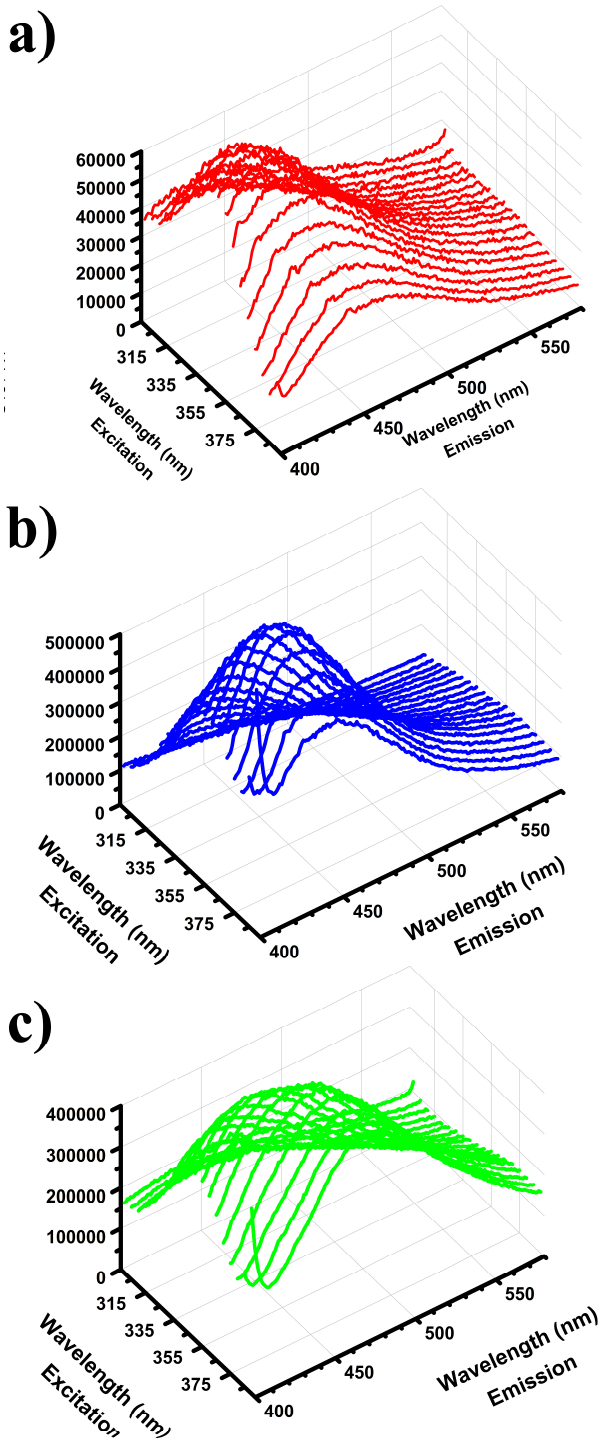

Figure S3. Additional photoluminescence data of each of the nanorods, as functions of excitation wavelength. a) D = 1.0 nm. b) D = 1.5 nm. c) D = 3.5 nm.

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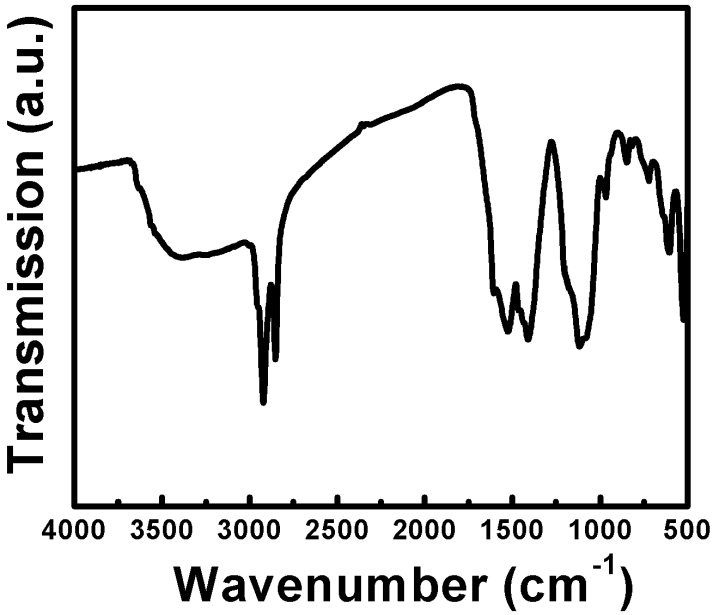

Figure S4. FTIR spectrum of $Eu_{2+x}O_2S$ NRs with a diameter of 3.5 nm and an aspect ratio of 5. It confirms that the surface ligand on $Eu_{2+x}O_2S$ NRs is oleate.

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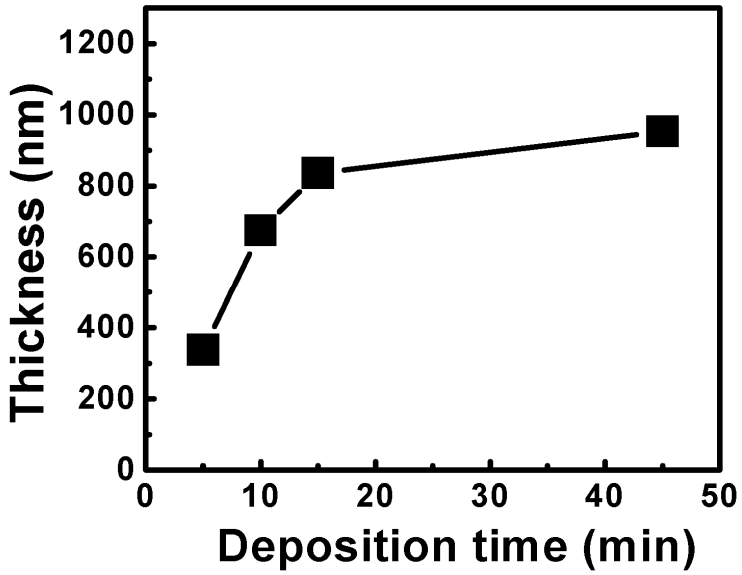

Figure S5. The plot of the thickness of $Eu_{2+x}O_2S$ NR electrophoretic deposition film versus deposition time. The diameter of the NRs is 3.5 nm and the aspect ratio of the NRs is 5. The applied voltage was 500 V and the NRs were suspended in hexane during deposition.