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Magnetic field enhanced upconversion luminescence and magnetic-optical hysteresis behaviors in $NaYF_4$: Yb, Ho nanoparticles

P. Chen,[a] Z. Zhong,[b] H. Jia,[c] J. Zhou,[d] J. Han,*[b] X. Liu,*[a] J. Qiu*[ae]

[a] State Key Laboratory of Modern Optical Instrumentation, School of Materials Science and Engineering, Zhejiang University, Hangzhou 310027, China

[b] Wuhan National High Magnetic Field Center, Huazhong University of Science and Technology, Wuhan 430074, China

[c] College of Physical and Electronic Information, Luoyang Normal College, 471022, Luoyang, Henan, P.R. China

[d] College of Materials Science and Engineering, China Jiliang University, Hangzhou 310018, China.

[e] State Key Laboratory of Luminescent Materials and Devices, South China University of Technology, Guangzhou 510640, China

Contents:

1. Experimental Section

$Y(Ac)_3 \cdot 4H_2O$ (99.99%), $Yb(Ac)_3 \cdot 4H_2O$ (99.99%), $Ho(Ac)_3 \cdot 4H_2O$ (99.99%) were purchased from Ansheng inorganic materials center Ganzhou in China. NaOH, NH_4F, 1-octadecene (ODE), and oleic acid (OA), SYLGARD silicone elastomer 184, curing agent were purchased from Sigma-Aldrich. Cyclohexane was purchased from Wako Pure Chemical Industries, Ltd. All of the chemicals were used as starting materials without further purification.

1.1 Synthesis of $NaYF_4$: 20%Yb, 1%Ho nanoparticles.

The $NaYF_4$: 20%Yb, 1%Ho nanoparticles were prepared by the co-precipitation method.[1] In a typical procedure, 3.16 mL $Y(Ac)_3 \cdot 4H_2O$, 0.80 mL $Yb(Ac)_3 \cdot 4H_2O$, 0.04 mL $Ho(Ac)_3 \cdot 4H_2O$ were mixed with 6 mL of OA and 14 mL of ODE in a 50 mL three-neck round-bottom flask. The resulting mixture was heated to 155 °C for 30 min to form a clear solution and then cooled down to room temperature. Thereafter, 10 mL of methanol solution containing 1.8 mmol NH_4F and 2.0 mmol NaOH was added, and the solution was stirred at 50 °C for 30 min. After methanol was evaporated, the solution was heated to 290 °C under Ar flow with vigorous stirring for 90 min and then cooled down to room temperature. The obtained nanoparticles were precipitated by ethanol, collected by centrifuged, washed with ethanol for several times, and finally re-dispersed in cyclohexane.

1.2 Synthesis of nanoparticles/PDMS composites.

The prepared nanoparticles were dispersed in 15 mL cyclohexane solution. The mixture liquid of SYLGARD silicone elastomer 184, curing agent and dispersed nanoparticles solution with the volume ratio of 10: 1: 1 were mixed for an hour, then aged overnight and heated at 85 °C for an hour to form a transparent solid.

1.3 X-Ray Diffraction (XRD) and High-resolution Transmission Electron Microscopy

(HRTEM)

XRD patterns of the dry powder was obtained on a RIGAKU D/MAX 2550/PC diffractometer (Japan) using Cu Kα radiation (λ = 1.5406 Å). HRTEM analysis was performed on a FEG-TEM (Tecnai G2 F30 S-Twin, Philips-FEI, Netherlands) operated at 300 kV.

1.4 Measurement of upconversion luminescence spectra under a pulse magnetic field

The luminescence spectra of nanoparticles were measured by the home-built luminescence spectroscopy system equipped with a pulsed magnetic field. The 975 nm laser was employed as the excitation source and coupled into a fiber to pump the nanoparticles. The nanoparticles were put at the center of the pulsed magnetic field generated by a resistive coil magnet. Luminescence spectra were collected by the same fiber system with the emitted photons transmitted to the detection part and detected by a spectrometer, which is equipped with an electron multiplying charge coupled device (CCD) detector.

2. Fig. S1

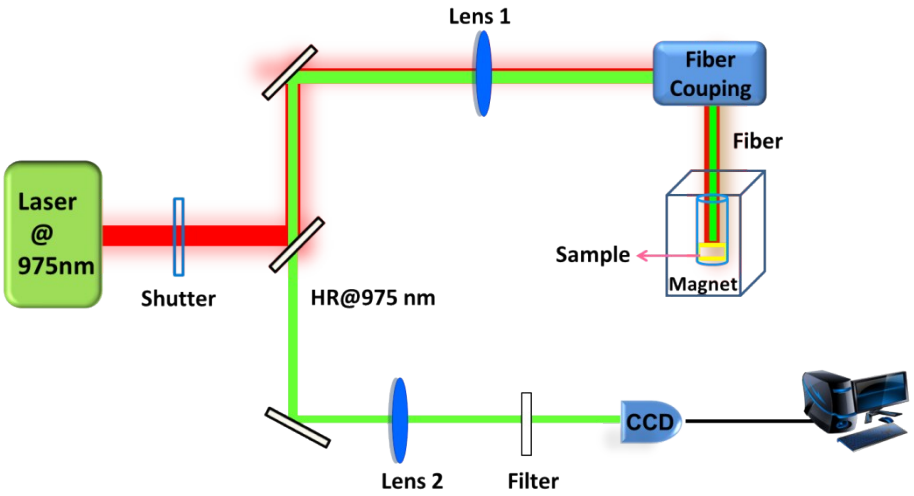

Fig. S1 Schematic diagram of luminescence spectroscopy test system equipped with a pulse magnetic field.[2]

The 975 nm laser was coupled into the fiber system and transmitted to the surface of sample. The sample was located at the center of the pulse magnetic field, which was generated by the liquid nitrogen-cooled resistive coil magnet. The magnetic field modulated upconversion luminescence from the $NaYF_4$: 20%Yb, 1%Ho nanoparticles was transmitted by the same fiber system with the spatial and spectral filtration, then detected by a spectrometer equipped with an electron multiplying charge coupled device (CCD) detector.

3. Fig. S2

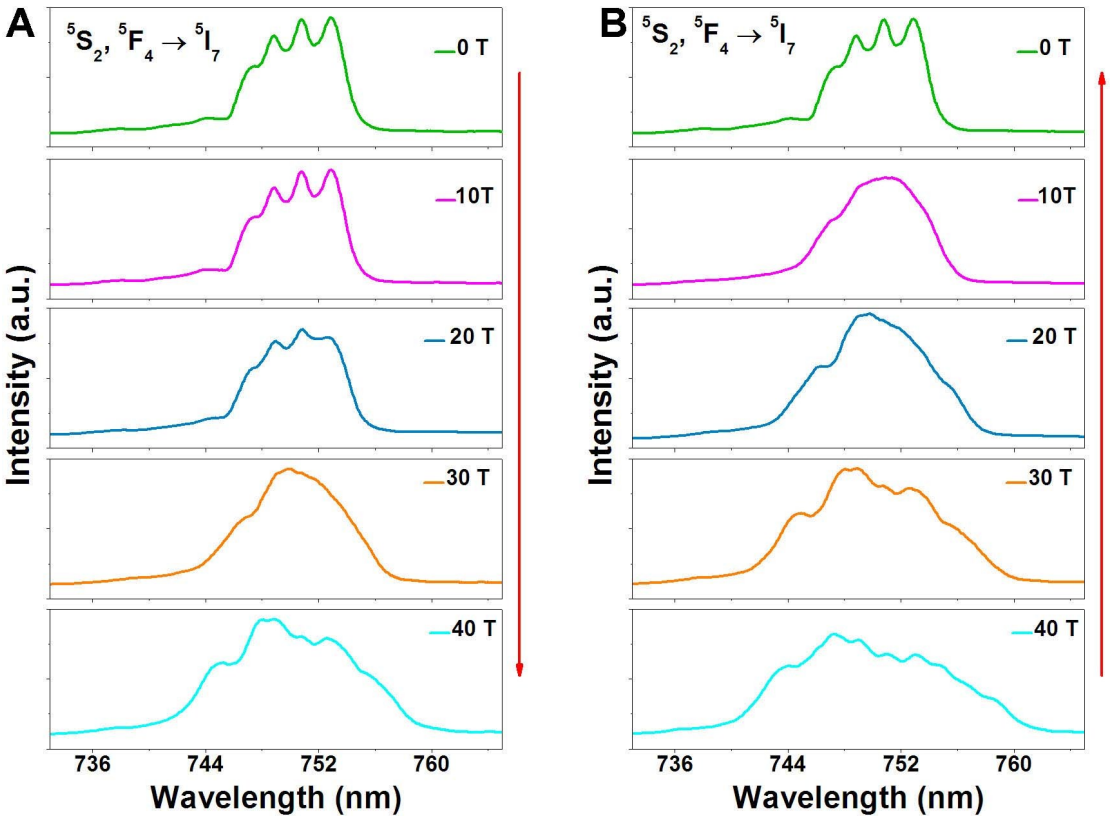

Fig. S2 Luminescence spectra of $NaYF_4$: 20%Yb, 1%Ho nanoparticles from the transition of $^5S_2$, $^5F_4 \rightarrow {}^5I_7$ with increasing (A) and decreasing (B) magnetic field.

4. Fig. S3

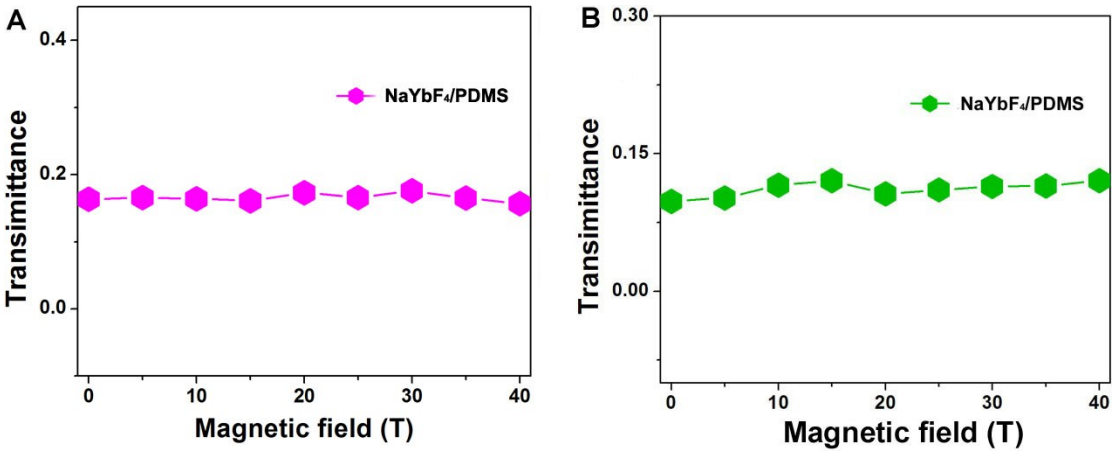

Fig. S3 Dependence of transmittance at 975 nm of PDMS doped with $NaHoF_4$ (A) and $NaYbF_4$ (B) nanoparticles on magnetic field intensity.

5. Fig. S4

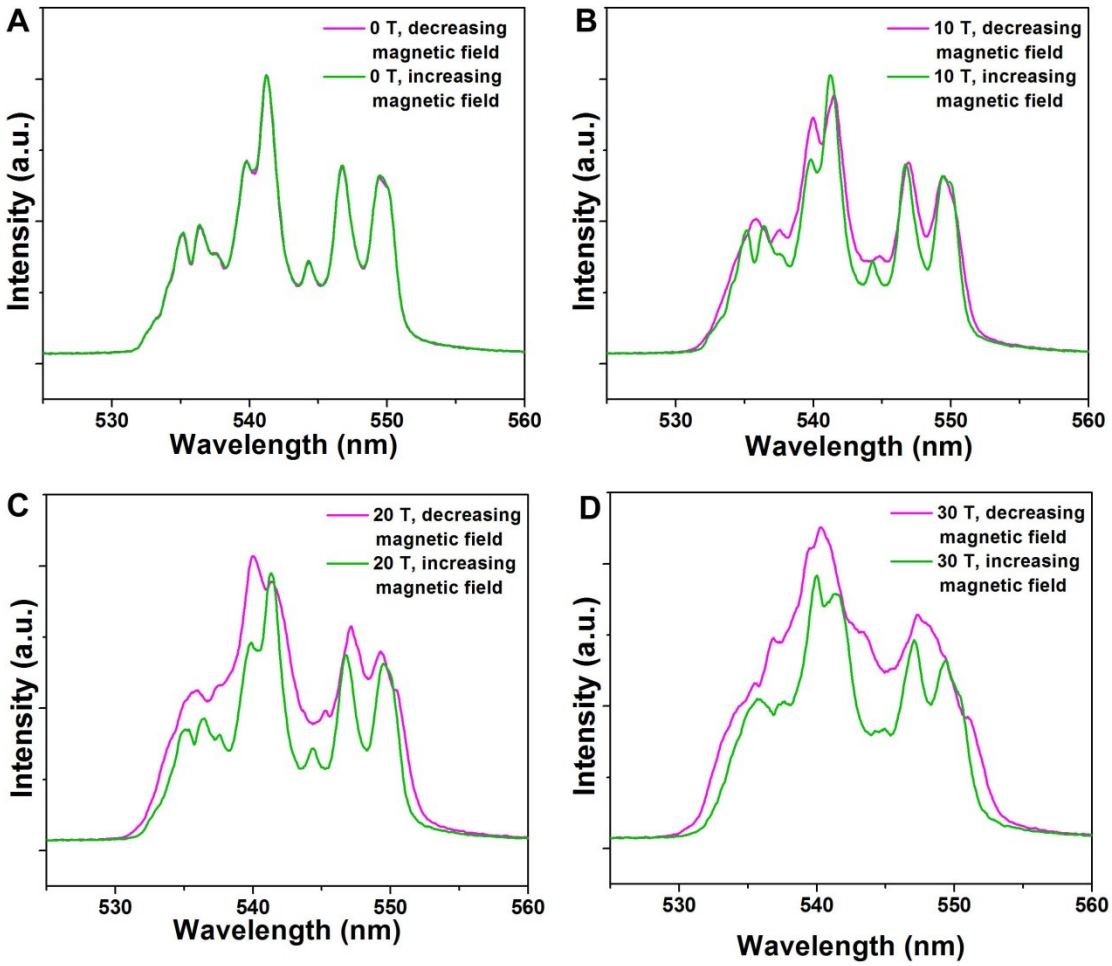

Fig. S4 Luminescence spectra of $NaYF_4$: 20%Yb, 1%Ho nanoparticles from the transition of $^5S_2$, $^5F_4 \rightarrow {}^5I_8$ of Ho^{3+} with different magnetic field intensity in the process of increasing and decreasing magnetic field, recorded at 90 K and the excitation at 975 nm.

6. Fig. S5

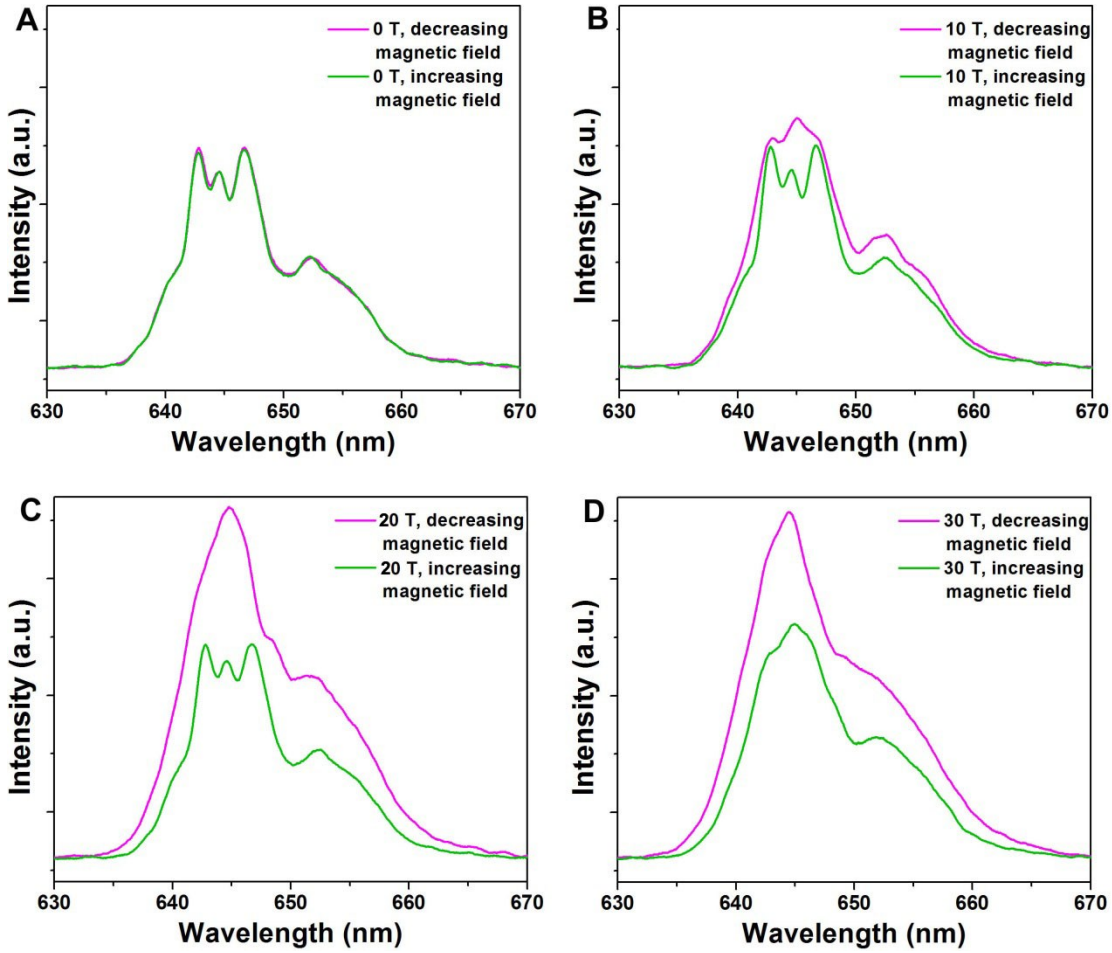

Fig. S5 Luminescence spectra of $NaYF_4$: 20%Yb, 1%Ho nanoparticles from the transition of $^5F_5 \rightarrow {}^5I_8$ of Ho^{3+} with different magnetic field intensity in the process of increasing and decreasing magnetic field, recorded at 90 K and the excitation at 975 nm.

7. Fig. S6

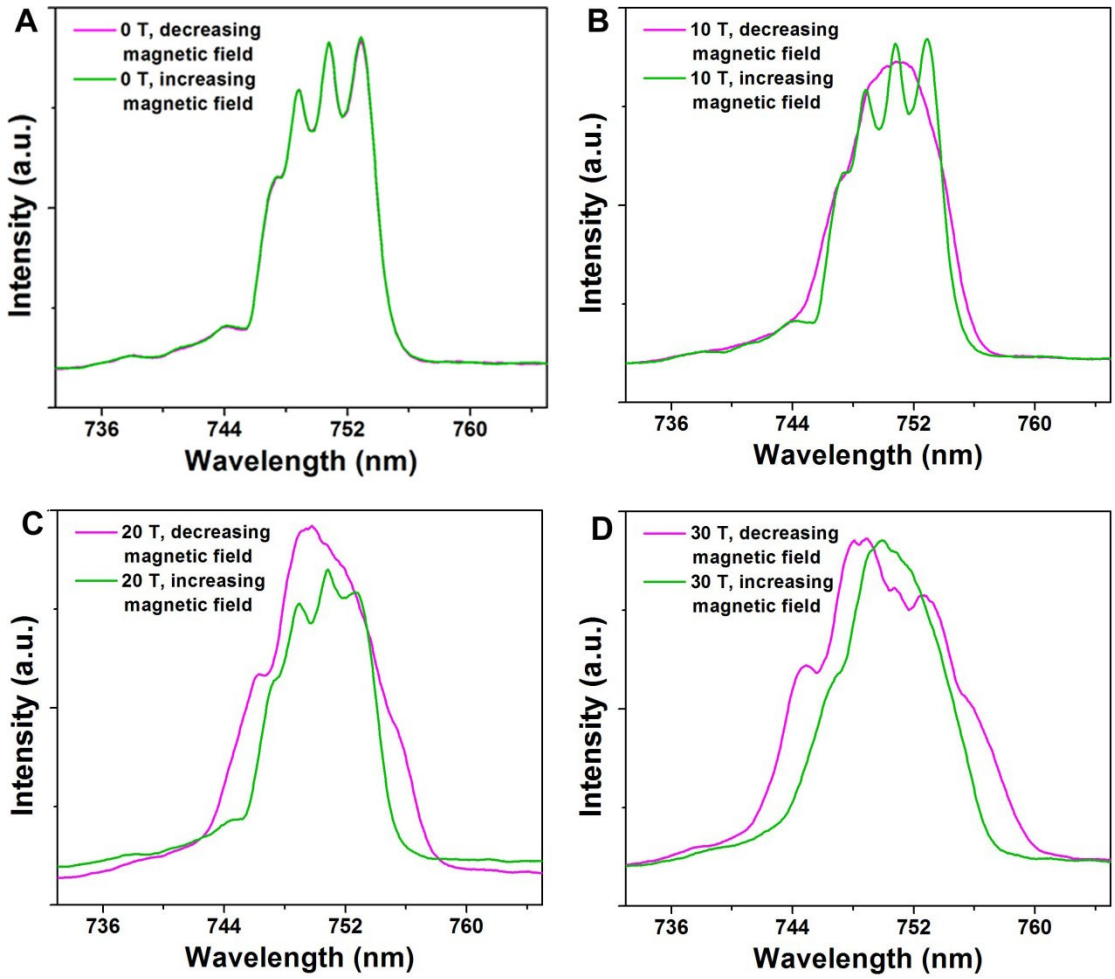

Fig. S6 Luminescence spectra of $NaYF_4$: 20%Yb, 1%Ho nanoparticles from the transition of $^5S_2$, $^5F_4 \rightarrow {}^5I_7$ of Ho^{3+} with different magnetic field intensity in the process of increasing and decreasing magnetic field, recorded at 90 K and the excitation at 975n m.

8. Fig. S7

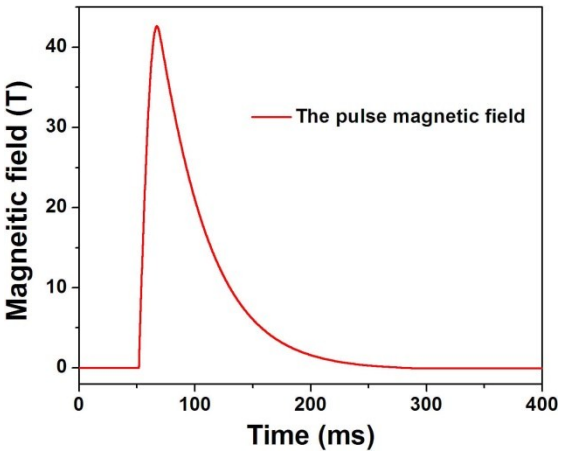

Fig. S7 Dependence of the magnetic field intensity of the pulse magnetic field on time.

9. Fig. S8

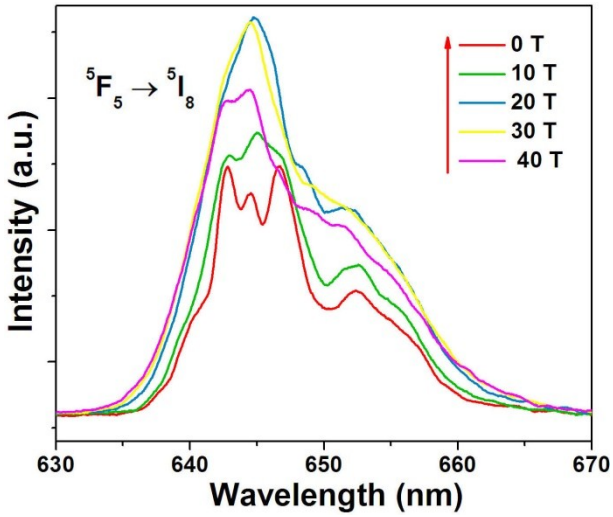

Fig. S8 Luminescence spectra of $NaYF_4$: 20%Yb, 1%Ho nanoparticles from the transition of $^5F_5$ $\rightarrow$ $^5I_8$ in the process of decreasing magnetic field.

10. REFERENCE

[1] F. Wang, Y. Han, C. S. Lim, Y.o Lu, J. Wang, J. Xu, H. Chen, C. Zhang, M. Hong, X. Liu,

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[2] P. Chen, H. Jia, Z. Zhong, J. Han, Q. Guo, J. Zhou, X. Liu, J. Qiu, *J. Mater. Chem. C,* 2015, **3**, 8794.