Tempered-Construction of Hollow MoS₂ Architectures with Improved Photoresponses

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Despite the outstanding optoelectronic properties of MoS₂ and its analogues, synthesis of such materials with desired features including fewer layers, arbitrary hollow structures, and particularly specifically customized morphologies, via inorganic reactions has always been challenging. Herein, using predesigned lanthanide-doped upconversion luminescent materials (e.g., NaYF₄:Ln) as templates, arbitrary MoS₂ hollow structures with precisely defined morphologies, widely variable dimensions, and very small shell thickness (∼2.5 nm) are readily constructed. Most importantly, integration of the near-infrared-responsive template significantly improves the photoresponse of up to 600 fold in device made of NaYF₄:Yb/Er@MoS₂ compared with that of MoS₂ nanosheets under 980 nm laser illumination. Multichannel optoelectronic device is further fabricated by simply changing luminescent ions in the template, e.g., NaYF₄:Er@MoS₂, operating at 1532 nm light excitation with a 276-fold photoresponse enhancement. The simple chemistry, easy operation, high reliability, variable morphologies, and wide universality represent the most important advantages of this novel strategy that has not been accessed before.

As a shining star among two-dimensional transition metal dichalcogenides (TMDs), MoS₂ and its composites have aroused impressive research enthusiasm due to their outstanding physical and chemical properties, such as large surface area, excellent electric conductivity, adjustable band gap, and tailorable density of active sites. Such superior features have imparted them great potentials in many applications including host materials for energy storage in metal ion batteries and super capacitors, catalysts for hydrogen evolution reactions, as well as devices for gas sensors, flash memories, and photodetectors.[1–10]

In virtue of its sandwich-like structure coupled by van der Waals forces and the in-plan S–Mo–S covalent bonding, numerous efforts have been invested aiming to exfoliate bulk MoS₂ into single or few-layered sheets to satisfy different requirements.[11,12] However, one of the serious challenges is that the exfoliated nanosheets are prone to reaggregate or restack when extracted from solution, causing even massier piling, such as twisted, folded, or broken pieces and resulting in significantly deteriorated performance.[13–15] Thus, MoS₂ architectures with large surface area, particularly those hollow structures with precisely designable and retainable configurations are highly demanded.[16–18] For example, Li et al. synthesized 100 nm thick hollow microcubical framework of MoS₂ with high specific capacity and large electrolyte/electrode contact for sodium storage,[16] Zhuo et al. constructed hierarchical MoS₂ nanotubes with a wall thickness of ∼50 nm through anion exchange and improved photocurrent was obtained,[17] Yu et al. fabricated cubic hollow MoS₂ structures with a thickness...
of ≈20 nm, aiming at maximizing the exposed edge sites to promote its catalytic activity.[19] Nonetheless, those architectures are still tens or hundreds of times thicker than the value (6.5 Å) characteristic of a single layer MoS$_2$, and there remains a large room for further improving the ratio of exposed surface area to the mass of MoS$_2$. Thus, hollow structures with even thinner shells possessing large surface-to-volume ratio, high percentage of exposed atoms, customizable morphologies, and thus better performance in electrochemical catalysis and enhanced sensitivities in optoelectronic devices are highly desired.

Meanwhile, although lanthanide-doped upconversion luminescent materials have been thoroughly studied for their unique optical response under near-infrared (NIR) illumination,[19–22] the simple inorganic chemistry of lanthanide fluorides for being used as template for MoS$_2$, hollow structure synthesis remains untouched. Specifically, templates with widely desirable morphologies and dimensions can be easily synthesized, and they can also be neatly removed by just soaking in acidic solution.[23] Thus, a series of arbitrary MoS$_2$ hollow structures with shells as thin as ≈2.5 nm and dimensions ranging from as small as 35 nm to as large as several micrometers, can all be reliably constructed. More intriguingly, upconversion luminescence (UCL) at the wavelength of 540 and 654 nm generated by doped Yb$^{3+}$/Er$^{3+}$ in the template under NIR light excitation (980 nm), falls completely within the absorption range of MoS$_2$ (350–950 nm), which facilitates efficient resonance energy transfer (ET) and significantly improves optoelectronic responses. Following the same design principle, it has also been possible to fabricate photodetectors working at other wavelength (1532 nm) by simply changing the luminescent ions of the template, demonstrating great potential for interdisciplinary applications.

As illustrated in Scheme 1, using the most thoroughly studied NaYF$_4$:Yb/Er (18/2 mol%) as a representative template, composites of NaYF$_4$:Yb/Er@MoS$_2$ possessing expected morphologies and dimensions are routinely obtained by mixing the presynthesized template with precursors for MoS$_2$ thin layer growth, and then submitting the resulting solution to a hydrothermal reaction. Corresponding hollow structures are left after removal of NaYF$_4$:Yb/Er template via a facile washing of the composite using diluted aqueous solution of HCl.

Figure 1a shows transmission electron microscopy (TEM) image of the as-synthesized MoS$_2$ nanosheets with typical interlayer distance of 0.658 nm. The scanning electron microscopy (SEM) image in Figure 1b indicates high uniformity of NaYF$_4$:Yb/Er microrods used as template for hollow MoS$_2$ microtube construction. X-ray diffraction (XRD) patterns of NaYF$_4$:Yb/Er@MoS$_2$ matches well with those of standard XRD data of each individual component (Figure 1c). Both the thin layers of MoS$_2$ and the encapsulated NaYF$_4$:Yb/Er microrods are easily seen in TEM image (Figure 1d), and the interface is clearly discernable in the zoomed-in TEM image (Figure 1e). The 0.710 nm interlayer distance in high-resolution TEM (HRTEM) image (Figure 1f) matches with that of MoS$_2$. This is also highly consistent with the elemental mapping results where a sharp edge between the distribution of Y, F, and S, Mo elements at one end of the microrod is manifested (Figure 1g; and Figure S1, Supporting Information). The microtubes are then obtained after removal of NaYF$_4$:Yb/Er template and the structural details of MoS$_2$ particularly the 0.713 nm characteristic interlayer distance are shown in Figure 1h–j. Compared with the value of 0.658 nm in pristine MoS$_2$, the increased interlayer distance is likely caused by the nonplanar stacking of individual MoS$_2$ layers. It is worth emphasizing that the morphology of microtubes was well retained and almost identical to that of template. We also affirmed that the hexagonal-phase structure was maintained in both MoS$_2$ microtubes and MoS$_2$ nanosheets as indicated in the XRD data (Figure S2, Supporting Information). It should be noted that the peak intensity attributed to the (002) lattice plane becomes weaker in MoS$_2$ microtubes than that in MoS$_2$ nanosheets. This suggests that MoS$_2$ microtubes might have fewer layers, which is also consistent with the high transparency seen in Figure 1h.[24,25]

The Raman spectrum of MoS$_2$ microtubes has two characteristic peaks at 380.4 and 403.9 cm$^{-1}$ (Figure S3, Supporting Information), which correlates to the in-plane ($E_{2g}^{1}$) and out-of-plane vibration ($A_{1g}$) mode of hexagonal MoS$_2$, respectively. The frequency difference between the $E_{2g}^{1}$ and $A_{1g}$ Raman modes is ≈23.5 cm$^{-1}$, which suggests very few layers of the MoS$_2$ microtube and agrees with the TEM results.[26] We also performed energy dispersive spectroscopy (EDS) characterization of the
Figure 1. a) TEM image of as-synthesized MoS2 nanosheets. b) SEM image of as-synthesized NaYF4:Yb/Er template. c) XRD patterns of NaYF4:Yb/Er@MoS2 composite and NaYF4:Yb/Er microrods. The top and bottom patterns are standard XRD patterns of NaYF4:Yb/Er and MoS2, respectively. d) TEM image of NaYF4:Yb/Er@MoS2 composite. e) Magnified TEM image of sample in (d). f) HRTEM image of MoS2 layer in NaYF4:Yb/Er@MoS2 composite shown in (e). g) Elemental mapping of the NaYF4:Yb/Er@MoS2 composite showing sharp distribution of Y, F and S, Mo. h) TEM image of MoS2 microtubes after removal of NaYF4:Yb/Er template. i) Magnified TEM image of sample in (h). j) HRTEM image of the edge of MoS2 microtube shown in (i). k) Zeta potential profile of ligand-free NaYF4:Yb/Er microrods and as-synthesized MoS2 nanosheets shown in (a).

as-synthesized hollow MoS2 microtubes (Figure S4, Supporting Information), where no signals ascribable to Na+, F−, or rare earth ions (RE3+) can be detected. This indicates that the template was completely removed by soaking in aqueous HCl solution followed by a thorough wash.

Zeta potential measurement shows positive charge in NaYF4:Yb/Er template, which originates from the exposed RE3+ when ligand molecules are stripped off from the microrod surface (Figure 1k).[27] The negative charge on MoS2 makes it prone to combine to the surface of NaYF4:Yb/Er through electrostatic attractions, enabling natural growth of MoS2 thin layers. However, since S2− is a soft base while RE3+ is a hard acid according to the theory of hard and soft acids and bases formulated by Pearson,[28,29] their combination is so weak that only small and isolated pieces of MoS2 can bind randomly on NaYF4:Yb/Er surface (Figure S5, Supporting Information), resulting in poor-quality of broken MoS2 hollow structures after template removal (Figure S6, Supporting Information).

To solve this problem, a surfactant molecule with stronger chelating capabilities to RE3+, i.e., a harder base, disodium salt of ethylenediamine tetraacetic acid (EDTA-2Na), was intentionally added into the reaction system. We expect that EDTA2− will bind firmly to RE3+ on the template surface and meanwhile help to fix MoS2 precursors (Mo6+ ions) from solution and further regulate the growth of MoS2 thin layers with improved quality,[30,31] when reaction conditions such as precursor concentration, reaction temperature, and growth time, are optimized. This also explains why the growth of MoS2 thin layers follows so closely to
the contour of the template (Figure 1h,i). Moreover, the very thin layer of hollow MoS₂ may favor higher density of active sites or electronic sensitivities than thicker analogues when used for photo- and/or electrochemical catalysis or optoelectronics.

The interactions between template and shell in NaYF₄:Yb/Er@MoS₂ composite were further studied using X-ray photoelectron spectroscopy (XPS). The binding energies of Mo 3d₃/₂ and Mo 3d₅/₂ in pure MoS₂ nanosheets located at 232.38 and 229.18 eV shifted to 231.74 and 228.34 eV in NaYF₄:Yb/Er@MoS₂ (Figure 2a; and Figure S7, Supporting Information), while those of S 2p₁/₂ and S 2p₃/₂ observed at 163.20 and 162.01 eV in pure MoS₂ nanosheets shifted to 162.74 and 161.54 eV (Figures S7 and S8, Supporting Information), respectively. This behavior is presumably caused by the increased electron cloud density of the outer orbitals of Mo⁴⁺ and S²⁻ ions, which suggests the presence of a strong electrostatic interaction between MoS₂ and NaYF₄:Yb/Er in the composite. More importantly, the respective binding energies for MoS₂ microtubes fell back to the values similar to those of pure MoS₂ nanosheets when NaYF₄:Yb/Er templates were removed (Figure S7, Supporting Information), which reversely confirms the existence of electrostatic interaction.

The complete spectral overlap between the UV–Visible–NIR absorption of MoS₂ and the UCL emissions of NaYF₄:Yb/Er under 980 nm laser excitation (Figure 2b; and Figure S9, Supporting Information) allows efficient nonradiative ET between the two components, which is reflected by the significantly decreased UCL intensity of NaYF₄:Yb/Er@MoS₂ compared with that of pure NaYF₄:Yb/Er (Figure 2c). As a control experiment, the UCL of NaYF₄:Yb/Er in its physical mixture with MoS₂ is still
Figure 3. a) Schematic illustration of the optoelectronic device fabricated using NaYF₄:Yb/Er@MoS₂ composite with channel length of 100 µm and width of 1000 µm. b) Dependence of the I–V curves on illumination power density of the device in (a), under 980 nm laser excitation. c) Temporal photocurrent responses of devices made of NaYF₄:Yb/Er@MoS₂ and MoS₂ nanosheets, respectively. d) Time-resolved photocurrent indicating the rise and decay time after 980 nm laser switching ON or OFF. e) Temporal photocurrent responses of devices made of MoS₂ microtubes and MoS₂ nanosheets, respectively. f) Photocurrent and responsivity of NaYF₄:Yb/Er@MoS₂ device as a function of illumination power density at 980 nm and voltage at 10 V.

observable, although greatly weakened (Figure 2c), which might be caused by the UCL reabsorption by MoS₂ as well as light scattering from small pieces of MoS₂. Accordingly, shortening of emission lifetimes at 540 and 654 nm from 243 and 494 µs in NaYF₄:Yb/Er to 182 and 416 µs in the composite, respectively, suggests the obvious ET from NaYF₄:Yb/Er to MoS₂, while no prominent lifetime change was detected in their physical mixture (Figure 2d,e). The efficiency of nonradiative ET process is estimated to be around 25% for ⁴S₃/₂ level and 15% for ⁴F₉/₂ level. Figure 2f depicts the nonradiative ET pathways where the energy responsible for UCL emissions is transferred directly to the closely bound MoS₂ thin layers. Moreover, the 1.276 eV bandgap of MoS₂ thin layers (Figure S10, Supporting Information) matches with both emissions at 540 and 654 nm of the microrods, which shall be responsible for the lifetime decrease (Figure 2d,e).

To showcase the improved NIR-response of 3D MoS₂ hollow architectures brought by the NIR-responsive template, a photodetector was fabricated (Figure 3a) using NaYF₄:Yb/Er@MoS₂ composite shown in Figure 1d. The optical image of the photodetector is displayed in Figure S11a (Supporting Information), of which the channel length and width is 100 and 1000 µm, respectively. The thickness of NaYF₄:Yb/Er@MoS₂ film is about 1 µm as shown in Figure S11b (Supporting Information). Current–voltage (I–V) measurements under dark and illumination conditions give linear characteristics at low voltage (Figure 3b), demonstrating a typical ohmic contact between the electrodes and the channel materials which makes bias voltage applied on the active channel rather than on the contact interface between electrode and channel material, and ensures high electrical responsivity. Comparison of Figure 3b and Figure S12 (Supporting Information) indicates that the dark current of the composite is much larger than that of pure MoS₂ nanosheets, suggesting higher electrical conductivity of the composite. The negative photoresponse in pure MoS₂ nanosheets (Figure S12, Supporting Information) is likely due to the competitive effects
between photogenerated charger carriers and photothermal effect.\textsuperscript{[36–38]} It should be noted that I-V curves of photodetector made of pure MoS\textsubscript{2} nanosheets showed Schottky-contacted characteristics (Figure S12, Supporting Information), while that of NaYF\textsubscript{4}:Yb/Er@MoS\textsubscript{2} composite showed ohmic-contact features (Figure 3b), which was likely due to the 3D structure of NaYF\textsubscript{4}:Yb/Er@MoS\textsubscript{2} compared to 2D MoS\textsubscript{2} nanosheets. Because the special 3D framework makes MoS\textsubscript{2} contacted with metal electrode mostly in the way of “top-contact,” while MoS\textsubscript{2} nanosheets mainly in the way of “top-contact” and the former style was recognized helpful for reducing contact resistance and improving electrical properties.\textsuperscript{[39–41]}

As an important parameter for NaYF\textsubscript{4}:Yb/Er@MoS\textsubscript{2} photodetector, the temporal response was recorded under excitation of a pulsed laser with time interval of 10 s. The highly repeatable and stable photocurrent under 980 nm laser irradiation was evidently enhanced in NaYF\textsubscript{4}:Yb/Er@MoS\textsubscript{2} composite by 600 folds compared with that of pure MoS\textsubscript{2} nanosheets at the illumination power density of 19.10 W cm\textsuperscript{-2} and voltage of 10 V (Figure 3c), which displays an excellent light switching functionality of this device. The time-resolved photocurrent rises accordingly with increased excitation power density or applied voltage (Figures S13 and S14, Supporting Information). The switching time for the photocurrent rise, defined as the time for the rise of the output signal from 0\% to 90\% of the maximal output value,\textsuperscript{[42]} is 0.72 s for NaYF\textsubscript{4}:Yb/Er@MoS\textsubscript{2} photodetector (Figure 3d), while the one for decay, defined as the time for the decrease from the maximal output value to 10\%, is 0.63 s (Figure 3d).

Only limited photocurrent can be generated in pure MoS\textsubscript{2} nanosheets under NIR (980 nm) excitation due to the comparatively large bandgap (1.276 eV). However, when the template NaYF\textsubscript{4}:Yb/Er was integrated in the photodetector, the synergetic effect derived from the 3D architecture of MoS\textsubscript{2} microtubes and non-radiative ET from NaYF\textsubscript{4}:Yb/Er greatly promotes the NIR photoresponse of MoS\textsubscript{2}. As a contrast, a 160-fold enhanced photoresponse was still obtained in photodetector made of MoS\textsubscript{2} microtubes (Figure 3e), which could be similarly attributed to the increased electric conductivity of the 3D structure compared with that of MoS\textsubscript{2} nanosheets.

MoS\textsubscript{2} can directly absorb illuminating photons above its band gap and generate charge carriers, and the photocurrent increases with the light intensity following the power-law of\textsuperscript{[43]}

\[
I_{ph} \propto I^n
\]

in which \(I_{ph}\) is the current when light is ON and \(I\) is the emission intensity of the NIR light source, which can be directly absorbed by MoS\textsubscript{2}. For NaYF\textsubscript{4}:Yb/Er@MoS\textsubscript{2}, \(I\) should be the intensity of UCL emitted from NaYF\textsubscript{4}:Yb/Er microrods, which is proportional to the excitation laser power density

\[
I \propto P_{ex}^n
\]

where \(n\) is defined as the number of photons required for UCL, and \(P_{ex}\) is the laser power density. Therefore, it can be figured out that

\[
I_{ph} \propto P_{ex}^n
\]

So for NaYF\textsubscript{4}:Yb/Er@MoS\textsubscript{2} photodetector, through exponential fit shown in Figure 3f, the calculated \(n\) is 1.14. The number of photons for green and red upconversion emissions were obtained by fitting the curve of emission intensity versus excitation power (Figure S15, Supporting Information). Because both green and red emissions can be absorbed by MoS\textsubscript{2}, we here applied the average photon number for green and red upconversion emission, \(n = 1.87\). Therefore the calculated value for \(m\) is 0.61, which falls within the range of 0 < \(m\) < 1, and suggests the typical semiconductor property involving electron–hole separation, trapping, and recombination.\textsuperscript{[44]} Moreover, the NIR response of this photodetector can be further amplified \(\approx 1.8\) folds (Figure S16a, Supporting Information) by coupling with Au nanorods at dimensions of 15 nm × 95 nm (Figure S17, Supporting Information), whose localized surface plasmon resonance matches exactly with the excitation wavelength of NaYF\textsubscript{4}:Yb/Er at 980 nm (Figure S16b, Supporting Information). This result, again, proves not only the critical role that the template plays but also the rationality of our design principle.

To further evaluate the photoresponse performance, responsibility (\(R\)), specific detectivity (\(D^*\)), and external quantum efficiency (EQE) were evaluated. \(R\) represents the electric response to excitation light and is defined as \(I_{ph}/A P_{ex}\), where \(A\) is the effective area of the detector. \(D^*\) stands for the ability of a photodetector in detecting weak signals, and is defined as \(RA^{1/2}/(2eI_{dark})^{1/2}\), where \(e\) is electron charge. EQE is defined as \(hcR/e\lambda\), where \(h\) is the Plank constant, \(c\) is the light velocity.\textsuperscript{[36–38]} Therefore we can deduce that the \(R\) of NaYF\textsubscript{4}:Yb/Er@MoS\textsubscript{2} photodetector kept increasing and reached steady state (Figure 3f) with laser power increasing. Moreover, compared with MoS\textsubscript{2} nanosheet photodetector, \(R\), \(D^*\), and EQE are increased from 0.268 × 10\textsuperscript{-3} mA W\textsuperscript{-1}, 9.3 × 10\textsuperscript{4} Jones and 0.34 × 10\textsuperscript{-4}\% to 166 × 10\textsuperscript{-3} mAW\textsuperscript{-1}, 560 × 10\textsuperscript{4} Jones and 210 × 10\textsuperscript{-4}\%, respectively. Table S1 (Supporting Information) also summarized previously reported results where we can find that our work shows similar or even better performance. However, we believe that after further optimization of the material design parameters, fabrication steps, and working conditions, devices made of NaYF\textsubscript{4}:Yb/Er@MoS\textsubscript{2} composite shall exhibit even better NIR photoelectric detectivity.

Taking advantage of the multiple absorption capability of Er\textsuperscript{3+}, the working wavelength of such photodetector can be readily tuned to another range. For example, in the photodetector made of NaYF\textsubscript{4}:Er@MoS\textsubscript{2}, where Er\textsuperscript{3+} is responsive to 1532 nm laser illumination (Figure S18, Supporting Information), a 276-fold photoresponse enhancement was obtained compared with that of pure MoS\textsubscript{2} nanosheets (Figure S19, Supporting Information). Similarly, this was also due to the ET from Er\textsuperscript{3+} in the template to the MoS\textsubscript{2} shell (Figure S20, Supporting Information) according to the lifetime changes of the luminescence emissions at 540 and 654 nm (Figure S21, Supporting Information), with efficiency of 22\% and 14\%, respectively. The photodetector made of MoS\textsubscript{2} microtubes gave a 155-fold improvement (Figure S19, Supporting Information) by coupling with Au nanorods at dimensions of 15 nm × 95 nm (Figure S17, Supporting Information), whose localized surface plasmon resonance matches exactly with the excitation wavelength of NaYF\textsubscript{4}:Yb/Er at 980 nm (Figure S16b, Supporting Information). This result, again, proves not only the critical role that the template plays but also the rationality of our design principle.

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Supporting Information] compared with that of NaYF₄:Yb/Er@MoS₂ excited with 980 nm laser (Figure 3c) because: 1) Er³⁺ has smaller absorption cross section (1.7 × 10⁻²¹ cm²) at 1532 nm) in NaYF₄:Er than that of Yb³⁺ (9.11 × 10⁻²¹ cm² at 980 nm) in NaYF₄:Yb/Er, and 2) the relatively low upconversion efficiency of Er³⁺ in NaYF₄:Er, which is a 3-photon upconversion process compared with a 2-photon process in NaYF₄:Yb/Er.

Due to the very close ionic radii and highly similar chemical properties of lanthanide ions, Gd³⁺ was intentionally codoped for more sophisticated dimension and morphology tuning of the templates. Following the same recipe, a wide variety of MoS₂ hollow architectures could then be readily obtained when NaYF₄:Ln (Ln = Yb/Er, 18/2 mol%) for nanoparticles, nanoplates, hexagonal prisms, and super microrods; Ln = Yb/Er/Gd, 18/2/30 mol%) for nanorods) with pre-designed dimensions and morphologies were used as templates (Figure 4), such as nanovesicles as small as 35 nm (Figure 4a,f,k), hollow hexagonal prisms with height varying from 50 (Figure 4b,g,l) to 240 nm (Figure 4c,h,m), nanotubes (Figure 4d,i,n), and super microtubes (Figure 4e,j,o), respectively. Detailed analysis of TEM images of the nanovesicles indicates only ≈2.5 nm average thickness of the MoS₂ shell (Figure S22, Supporting Information), which is so far the smallest value ever reported. Moreover, it is worth emphasizing that not only the thin layer grows very uniformly along the templates, the structural details such as the 120° internal angle (Figure 4l,m) of the hollow hexagonal prism, and the sharp end of the super microtube (Figure 4o) derived from respective templates, were also perfectly retained in the hollow architectures. This, on the other hand, reflects perfect control for high quality hollow architecture synthesis originated from the sufficient affinity between MoS₂ and NaYF₄:Ln, and introduction of Gd³⁺ does not affect the quality of the composite or template removal. Such widely designable hollow architectures may possess great potentials in drug delivery, energy storage, thin film separation, as well as electrochemical and/or photocatalysis.

In conclusion, we have developed a facile and reliable template-based strategy for arbitrary construction of hollow MoS₂ architectures with dimensions ranging from as small as ≈35 nm to up to as large as ≈10 µm, and morphologies ranging from nanoscaled vesicles to microsized tubes. This is the first time that easy fabrication of various MoS₂ hollow structures with shells as thin as ≈2.5 nm was ever accessed. As an added value, the lanthanide template is able to upconvert the NIR excitation energy and transfer efficiently to the MoS₂ shell, which can be further exploited for the development of multichannel NIR photodetectors. Moreover, the strategy developed here should inspire further constructions of other TMD hollow architectures with outstanding performances not only in optoelectronics, but also potentially in energy storage and photo-/electrochemical catalysis, which are ongoing projects in our lab.
Supporting Information

Supporting Information is available from the Wiley Online Library or from the author.

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Conflict of Interest

The authors declare no conflict of interest.

Keywords

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