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Lanthanide-based downshifting layers tested in a solar car race

Sandra F. H. Correia¹, Ana R. N. Bastos¹, Lianshe Fu¹, Luís D. Carlos¹,
Paulo S. André^{2,3*} and Rute A. S. Ferreira^{1*}

¹Department of Physics and CICECO - Aveiro Institute of Materials, University of Aveiro, 3810-193 Aveiro, Portugal; ²Department of Electric and Computer Engineering and Instituto de Telecomunicações, Instituto Superior Técnico, Universidade de Lisboa, 1049-001 Lisbon, Portugal; ³Department of Electronics, Telecommunications and Informatics, Instituto de Telecomunicações, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal.

* Correspondence: P S André, E-mail: paulo.andre@av.it.pt; R A S Ferreira, E-mail: rferreira@ua.pt

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Supplementary information for this paper is available at <https://doi.org/10.29026/oea.2019.190006>

Section 1: Synthesis of the $\text{Eu}(\text{tta})_3 \cdot 2\text{H}_2\text{O}$ complex

The synthesis of the $\text{Eu}(\text{tta})_3 \cdot 2\text{H}_2\text{O}$ complex is fully described elsewhere^{1,2}. 1 mmol (0.3662 g) of $\text{EuCl}_3 \cdot 6\text{H}_2\text{O}$ was dissolved in 1.5 mL of ethanol under stirring. Then, 3 mmol (0.6664 g) of Htta were added dropwise to the ethanolic solution of $\text{EuCl}_3 \cdot 6\text{H}_2\text{O}$. The pH of this solution was adjusted to 6–7 by adding an appropriate amount of an ethanolic NaOH solution. The resulting mixture was stirred for 24 h at room temperature and then the solvent was slowly evaporated during 48 h. The yellow solid obtained was washed with water and hexane and recrystallized in EtOH and dried at 45 during 48 h.

Section 2: Bare photovoltaic cells performance

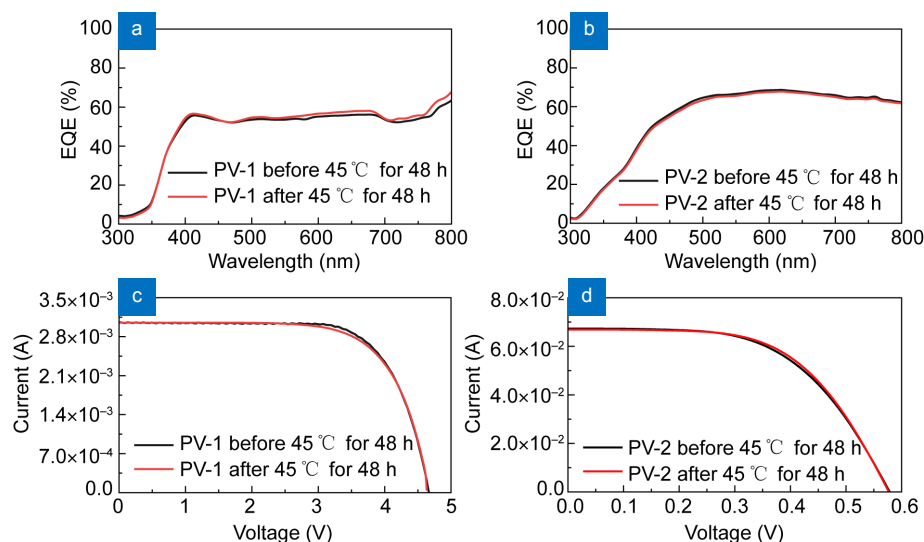


Fig. S1 | EQE (top) and V-I curves (bottom) of the bare (a, c) PV-1 and (b, d) PV-2 devices prior and after the heat treatment at 45 °C for 48 h.

Section 3: Coating thickness measurements

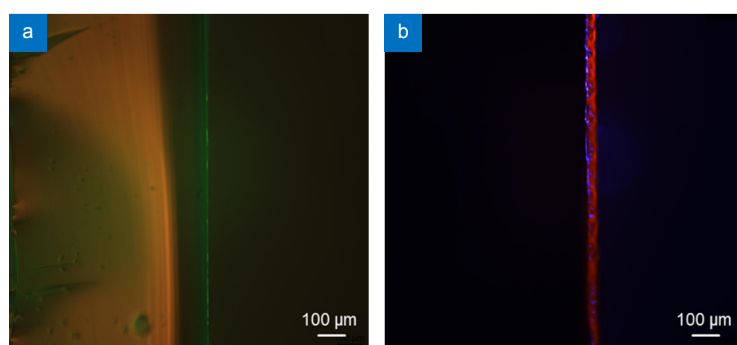


Fig. S2 | Cross-section optical microscopy images of (a) dU6-Tb and (b) tU5-Eu LDS layers on glass substrates under UV radiation at 365 nm.

Section 4: Spectroscopic ellipsometry

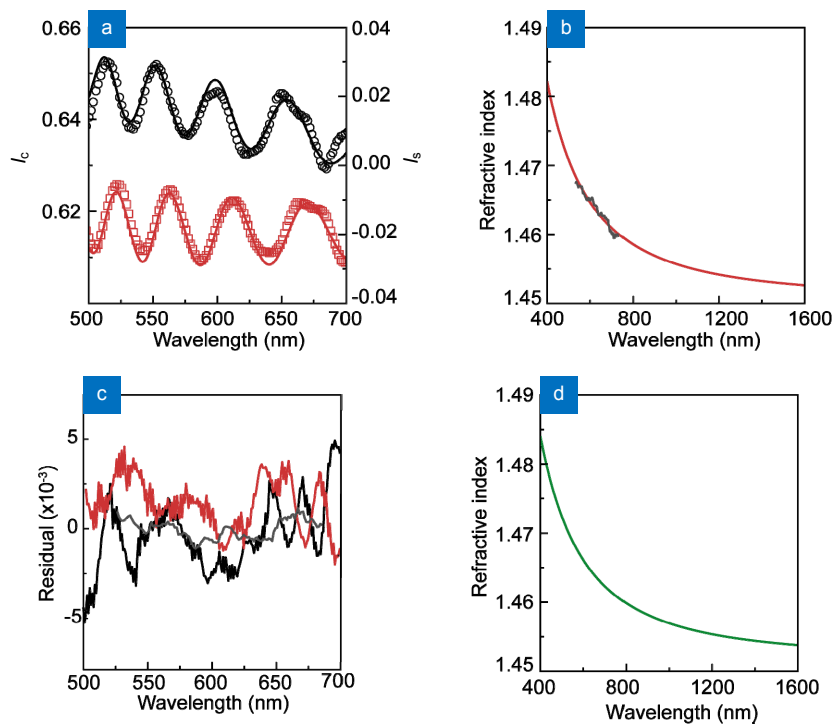


Fig. S3 | Ellipsometry parameters I_c (black) and I_s (red) for (a) dU6-Tb and refractive index dispersion curve for (b) tU5-Eu. The solid lines represent the data best fit ($r^2=0.9$); (c) Fit residual plots for I_c (black) and I_s (red) parameters, and refractive index (grey); (d) Refractive index dispersion curves of dU6-Tb.

Section 5: Coated photovoltaic cells

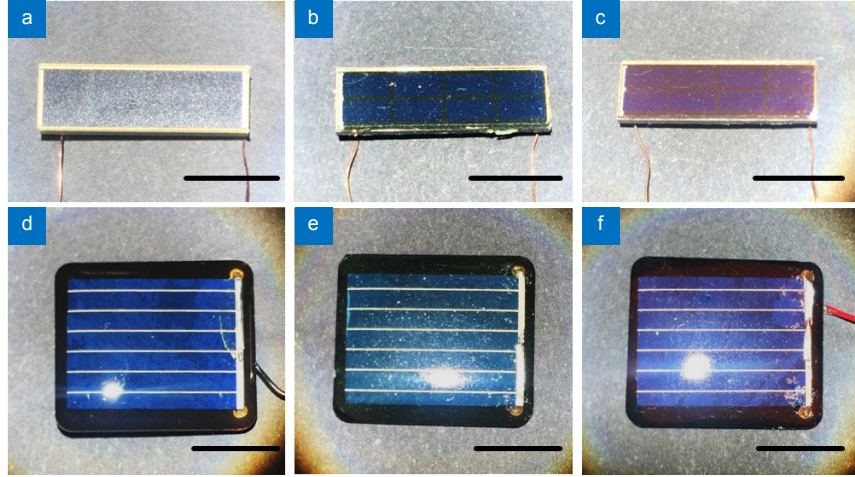


Fig. S4 | Photographs of the (a, d) bare PV devices and of the coated (b, c) PV-1 and (e, f) PV-2 with the (b, e) dU6-Tb and (e, f) tU5-Eu LDS coatings, under AM1.5G radiation. Scale bars: 10^{-2} m.

Absolute EQE curves

To infer about the contribution of the undoped material for the EQE of the PV devices, an undoped layer was deposited on top of a PV cell. For that, the synthetic conditions had to be changed comparing with the ones used to prepare the doped organic-inorganic hybrids: by using analogous conditions in both situations, the undoped layer does not become a gel requiring the use of higher amount of acid catalyst (or higher concentration) or aging at higher temperatures. Thus, for the synthesis of the undoped hybrid, 1.20 mL of EtOH was added to 3.0 g of t-UPTES(5000) precursor in the presence of 8.6×10^{-2} mL of HCl 1M and the deposition was performed by drop-casting. The EQE curves presented in Fig. S5 reveal no significant changes, reinforcing that the main contribution for the PV cells enhancement in the presence of the LDS layers arises from the UV-converted photons.

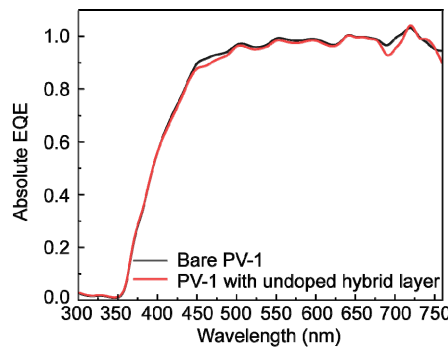


Fig. S5 | Absolute EQE curves of a bare PV-1 device and a PV-1 device coated with undoped organic-inorganic hybrid.

Short-circuit current (I_{sc})

The experimental relative increase in I_{sc} in the 300 to 360 nm spectral range was inferred through:

$$\Delta I_{sc} = \frac{\int_{300}^{360} I_{sc, coated} d\lambda - \int_{300}^{360} I_{sc, bare} d\lambda}{\int_{300}^{360} I_{sc, coated} d\lambda} \times 100 \quad , \quad (S1)$$

in which $I_{sc, coated}$ is the I_{sc} generated by the PV device with the LDS coating and $I_{sc, bare}$ is the I_{sc} generated by the bare PV device.

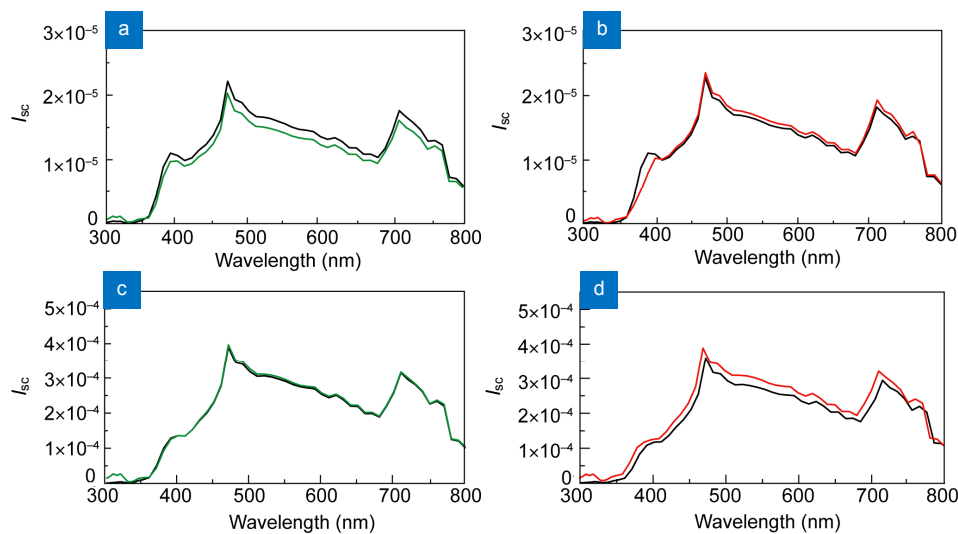


Fig. S6 | I_{sc} curves of (a, b) PV-1 and (c, d) PV-2 devices with (a, c) dU6-Tb (green lines) and (b, d) tU5-Eu (red lines) coatings compared with the bare PV devices (black lines).

Table S1 | EQE increase over the AM1.5G spectra (in the 300 to 800 nm spectral range) of the coated PV devices.

PV cell	LDS coating	$\Delta EQE_{AM1.5G}$
PV-1	tU5-Eu	4%
	dU6-Tb	8%
PV-2	tU5-Eu	9%
	dU6-Tb	1%

Section 6: Solar race

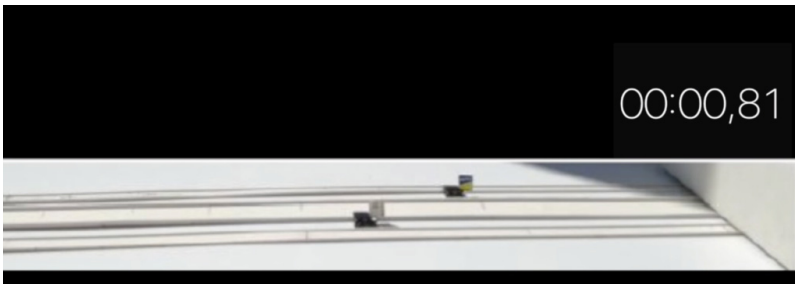


Fig. S7 | Stop motion video of the solar race with indication of elapsed time. The solar vehicle with the coated PV cell is indicated by the yellow identification tag. The full video is found as Electronic Supplementary Information

References

1. Molina C, Dahmouche K, Messaddeq Y, Ribeiro S J L, Silva M A P *et al.* Enhanced emission from Eu(III) β -diketone complex combined with ether-type oxygen atoms of di-ureasil organic–inorganic hybrids. *J Lumin* **104**, 93–101 (2003).

2. Correia S F H, Lima P P, André P S, Ferreira R A S, Carlos L D. High-efficiency luminescent solar concentrators for flexible waveguiding photovoltaics. *Sol Energy Mater Sol Cells* **138**, 51–57 (2015).