Supporting information

BCNO silica gel based green transparent and efficient luminescence down shifting layer for Si solar cell

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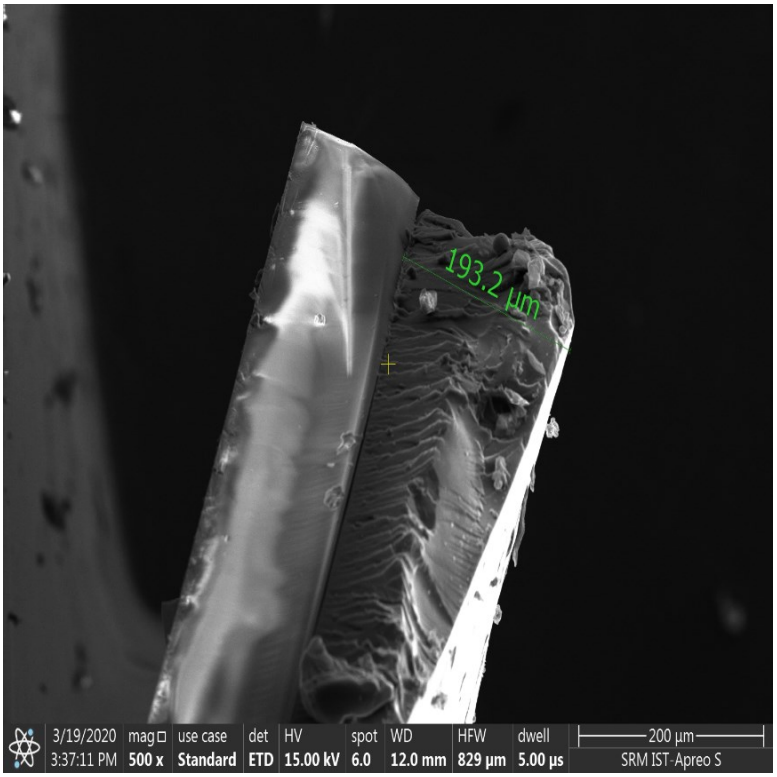


FigureS1. Cross-section SEM image of BCNO silica gel (LDS layer) coated on a glass substrate.

Quantum yield measurement

The quantum yield of BCNO silica gel was measured in liquid mode using integrating sphere. The sample for the measurement was prepared using ethanol as the solvent. 100µL of BCNO silica gel was added to 5ml of ethanol followed by stirring for 10 minutes at room temperature. The excitation and emission spectra was recorded for both blank and BCNO

silica gel sample. Finally the quantum yield of BCNO silica gel was obtained by using these measured spectra as inputs in quanta pi software of the Flurolog system.

Photostability test

To assess the photostability of the BCNO silica gel, aging test was carried out under the illumination of UV light (354 nm, 100 W cm^{-2} irradiance) in ambient for 250 and 500 hours. As shown in Figure (S2), there was about ~35% decrease in the emission intensity for the BCNO silica gel after 250 hours of UV exposure and the decrease was 55% after 500 hours of UV irradiance. The observed photostability of the BCNO silica gel, exhibiting the emission property even after 500 hours of UV irradiation, indicates that it can be an good alternative material for LDS layers as compared to the reported luminophores[1, 2, 3]. The photostability can be improved further by designing appropriate ligand structure[4, 5].

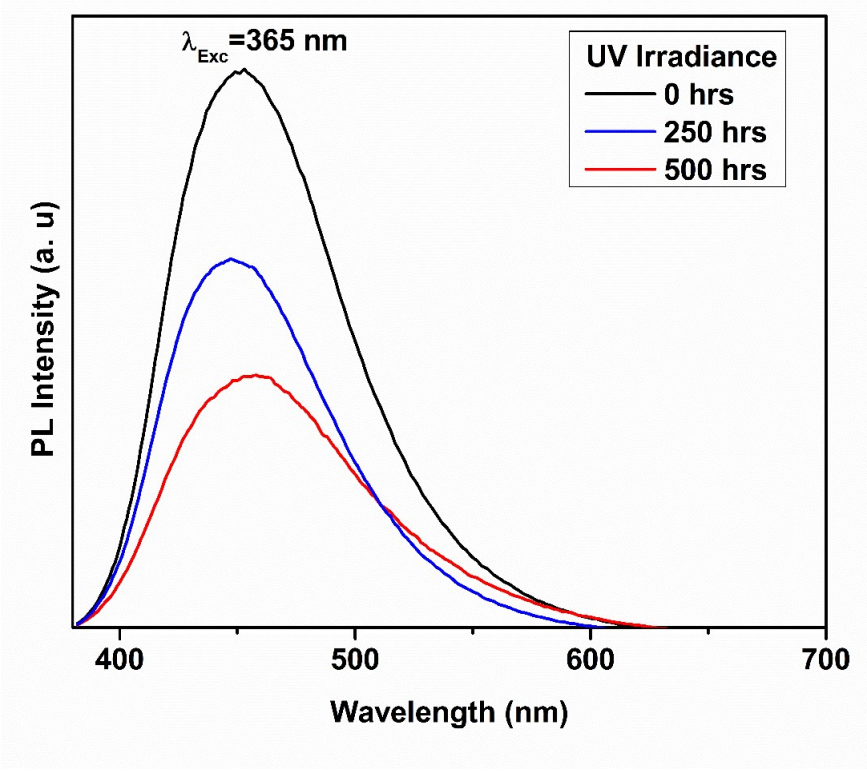
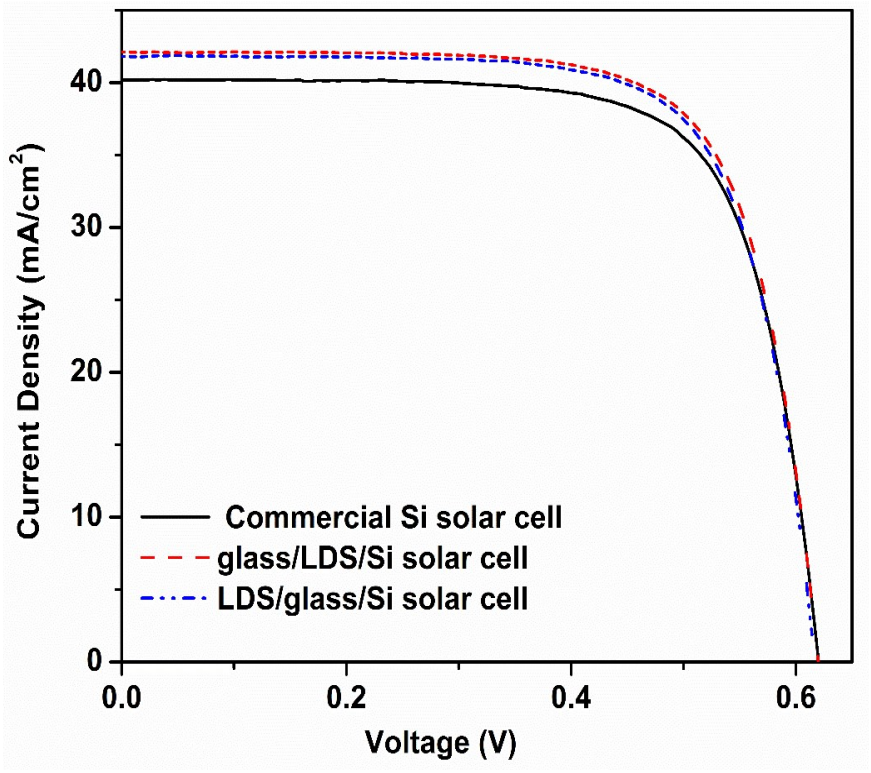


Figure S2. Photoluminescence spectra of BCNO silica gel under UV-irradiation (100W cm^{-2})

Measurements with commercial Si solar cell

The performance of BCNO silica gel LDS layer was also tested using a commercial Si solar cell. The current density-voltage (J-V) curves of the commercial Si solar cell were recorded with and without the LDS layer at standard testing conditions and the results were compared. The values of the photovoltaic parameters such as Voc, Jsc, fill factor (FF) and power conversion efficiency (PCE) as obtained from the measurements were tabulated(table S1). The performance of LDS layer was again proved with the commercial Si solar cells, leading to the enhancement of PCE from 18% to 18.8 % for glass/LDS layer/Si-solar cell configuration and from 18% to 18.6 % for LDS layer/glass/Si-solar cell configuration.



FigureS3. Current-Voltage characteristics of commercial Si solar cell with BCNO silica gel layer.

Table S1. Performance parameters of Si-solar cell with and without the BCNO silica gel LDS layer, compared with reports in literature using other LDS layers with Si solar cell.

	Voc (mV)	Jsc (mA/cm^2)	Fill factor (%)	Efficiency (%)	Percentage of improvement	
Si-solar cell (ref)	616 ± 1.55	30.6 ± 0.18	72.04 ± 0.007	13.61 ± 0.11		(our work)
LDS layer/glass/Si-solar cell	616 ± 1	31.83 ± 0.36	72.18 ± 0.06	14.15 ± 0.17	3.8%	
glass/LDS layer/Si-solar cell	617 ± 0.5	32.80 ± 0.1	72.20 ± 0.06	14.60 ± 0.05	7.1%	
Commercial Si-solar cell (ref)	619	39.99	72.7	18		
LDSlayer/glass/commercial solar cell	616	41.63	72.61	18.64	3.3%	
glass/LDSlayer/commercial solar cell	619	41.9	72.64	18.85	4.5%	
Si Solar cell (ref) Si Solar cell with CdSe/CdS QDs	543.4 ± 6.8 545.9 ± 3.4	32.5 ± 0.6 37.0 ± 0.6	68.0 ± 0.9 67.0 ± 1.0	12.0 ± 0.2 13.5 ± 0.2	11.7%	(ref# 53)
c-Si solar cell (ref) c-Si SC with LDS layer (CH_3 NH_3 $PbBr_3$ quantum dots)	590 600	38.67 40.23	61.6 62.1	14.05 14.99	5.8%	(ref# 55)
mc-Si solar cell (ref) mc-Si SC with LDS layer(CH_3 NH_3 $PbBr_3$ quantum dots)	570 590	32.35 33.02	56.6 58.1	10.44 11.32	8.2%	
c-Si solar cell (ref) c-Si solar cells coated with LDS layer ($Eu(tta)_3$pybox)	-- --	35.8 36.1	69.2 69.1	15.2 15.3	0.65%	(ref# 56)
mc-Si solar cell (ref) mc-Si cell/EVA/$Gd_2O_2S:Tb^{3+}$	604.6 608.0	37.85 38.81	71.81 72.15	16.43 17.02	3.6%	(ref#57)
Si solar cell (ref) Si solar cell with LDS ($Ba_2SiO_4:Eu^{2+}$)	600 600	41.18 41.51	68 68	17.06 17.25	1.1%	(ref#58)
Si Solar Cell (ref) Si Solar cell /Eu-doped silicate phosphor-610 nm	542.3 549.1	28.24 32.50	78.21 77.01	11.97 13.74	13.7%	(ref#59)

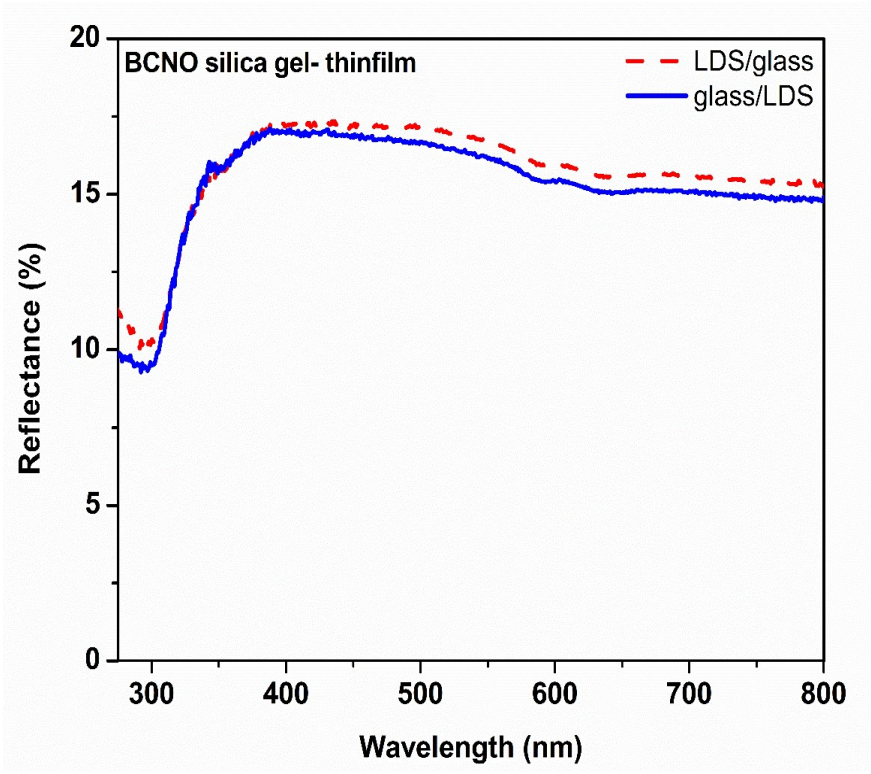


Figure S4. Reflectance spectra of BCNO silica gel LDS layer /glass and glass/BCNO silica gel LDS layer.

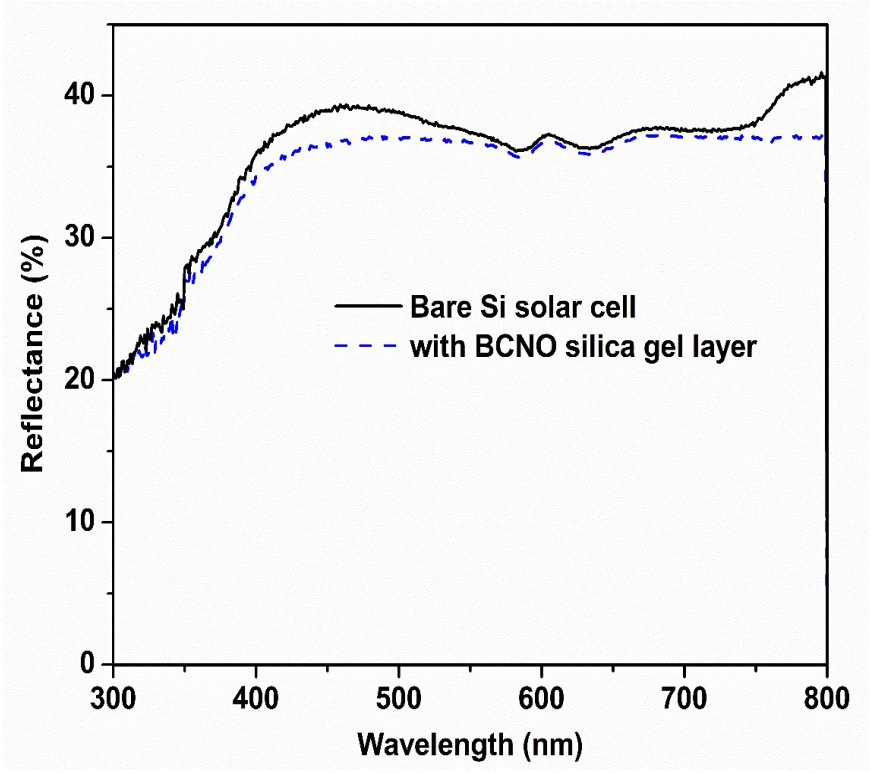


Figure S5. Reflectance from the surface of the Si solar cell with and without BCNO silica gel layer.

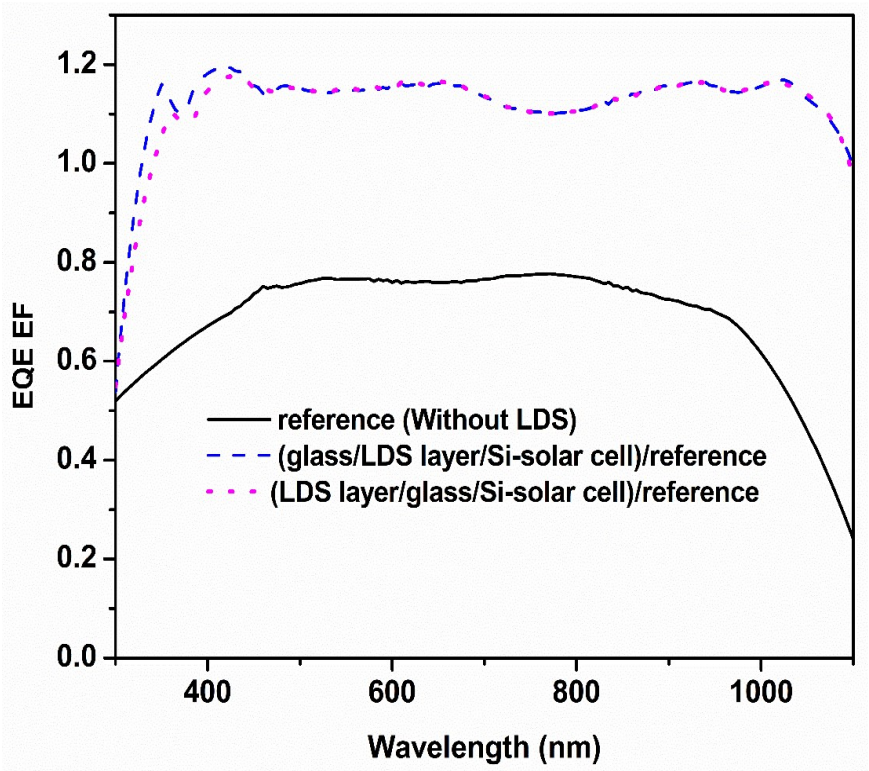


Figure S6. External quantum efficiency Enhancing Factor of BCNO silica gel LDS layer.

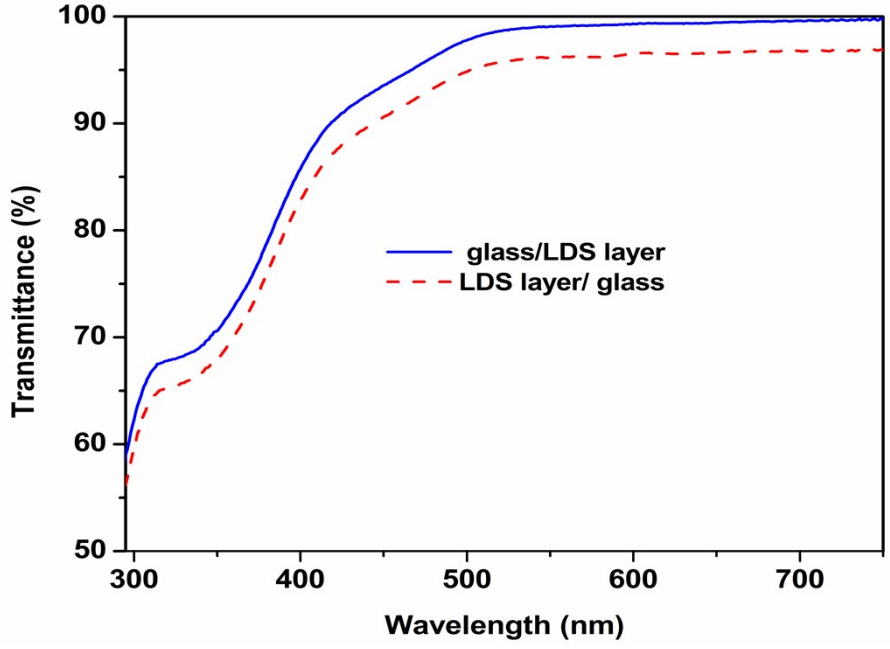


Figure S7. Transmittance spectra of BCNO silica gel layer in both LDS layer/glass and glass/LDS layer configurations.

References

1. L. Meng, X.G.Wu, S. Ma, L. Shi, M. Zhang, L. Wang, H. Zhong. Improving the efficiency of silicon solar cells using in situ fabricated perovskite quantum dots as luminescence downshifting materials. *Nanophotonics,* 2019, **9(1),** 93–100.
2. E. Moretti, A. Talon, L. Storaro, A. Le Donne, S. Binetti, A. Benedetti, S. Polizzi. Concentration quenching and photostability in $Eu(dbm)_3phen$ embedded in mesoporous silica nanoparticles. *Journal of Luminescence,* 2014,**146,** 178–185.
3. K. Binnemans. Lanthanide-Based Luminescent Hybrid Materials. *Chemical Reviews,* 2009, **109(9),** 4283–4374.
4. H. Wei, Z. Zhao, C. Wei, G. Yu, Z. Liu, B. Zhang, J. Bian, Z. Bian and C. Huang. Antiphotobleaching: A Type of Structurally Rigid Chromophore Ready for Constructing Highly Luminescent and Highly Photostable Europium Complexes, *Adv. Funct. Mater.* 2016, **26,** 2085–2096.
5. Y. Wang, P. G. Wilczynsk, X. Zhang, J. Yin, Y. Wen and H. Li. Photovoltaic efficiency enhancement of polycrystalline silicon solar cells by a highly stable luminescent film. *Sci China Mater* 2020, **63(4)**, 544–551.