

SUPPORTING INFORMATION

FROM WASTE TO ENERGY: LUMINESCENT SOLAR CONCENTRATORS BASED ON CARBON DOTS DERIVED FROM SURGICAL FACEMASKS

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Materials and methods

For the synthesis of C-Dots, it was used hydrogen peroxide solution 30% w/w, purchased from MERCK. For fabricating the LSC, the reagents were ethylene glycol dimethacrylate 98%, lauroyl peroxide for synthesis, and lauryl methacrylate 96%, all of them purchased from Sigma-Aldrich.

Photophysical studies of liquid C-Dots had been performed in air-equilibrated dichloromethane solution at room temperature using quartz cuvettes with 1.0 cm path length. For both liquid and solid state measurements, UV/Vis absorption spectra were recorded with a Jasco V-560 spectrophotometer. For luminescence measurements, we used a Jobin Yvon-Spex Fluoromax P spectrofluorimeter equipped with a Hamamatsu R3896 photomultiplier. For correcting the emission spectra for the photomultiplier response, a program purchased with the fluorimeter was used. To measure the luminescence lifetimes, an Edinburgh OB 900 time-correlated single-photon-counting spectrometer was used, and a Hamamatsu PLP 2 laser diode (59 ps pulse width at 408 nm) was employed as excitation source. Lifetimes uncertainties are about 10%, absorption spectra are registered with 2 nm of uncertain.

Synthesis of C-Dots

Carbon dots were synthesized from wasted facemasks via hydrothermal procedure. After having removed the elastic wires, the masks had been crushed into tiny pieces using a grinder. The material

was dried under reduced pressure and about 20 g were dispersed in 500 mL of hydrogen peroxide aqueous solution at 5% by volume. The suspension was left under constant magnetic stirring for 72 hours at room temperature. Approximately 1 g of treated masks was taken from the suspension and placed in a Teflon vessel (30 mL). Then 10 mL of deionized water and 3 mL of 30% hydrogen peroxide solution were added to the masks. More than one vessel had been prepared under the same procedure. The vessels were sealed in steel autoclave and then they were introduced in a sand bath allowing the temperature to reach 200°C in 3 hours, see **Figure S.1**. After 5 hours, the reactor is shut down and let it cold down slowly (about 10 hours).



Figure S.1. On the left, the mashed facemasks. On the right panel, the vessels dived in the sand bath during the hydrothermal process.

The so-obtained suspension had been filtered to remove the residues of the facemasks and then the solution of C-Dots had been extracted using dichloromethane. The final solution is yellow colored and had been characterized¹ by SEM and by photophysical measurements (including absorption spectra, steady-state luminescence spectra, excited state lifetime, and IR spectra). This synthetic procedure was followed three times, leading to repeatable results.

IR measurement

Fourier Transform Infrared (FT-IR) spectra in Attenuated Total Reflectance (ATR) were acquired with Perkin-Elmer Spectrum Two spectrometer with a diamond ATR single reflection accessory, in the spectral range between 4000 and 400 cm^{-1} (wavenumbers), with a resolution of 4 cm^{-1} and 64 scans per sample.

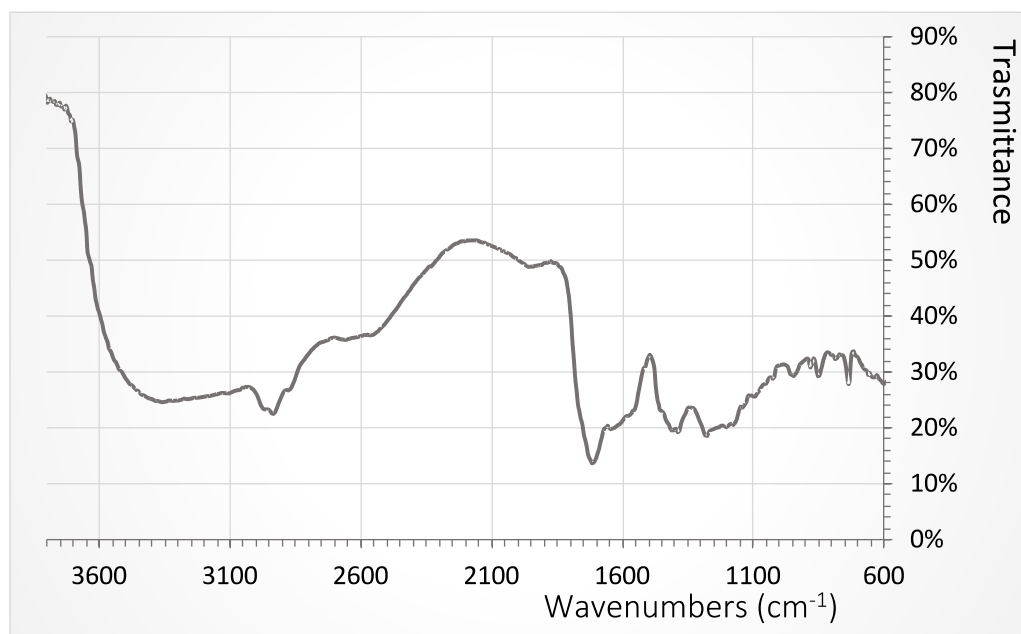


Figure S2. IR spectrum in solid state of C-Dots.

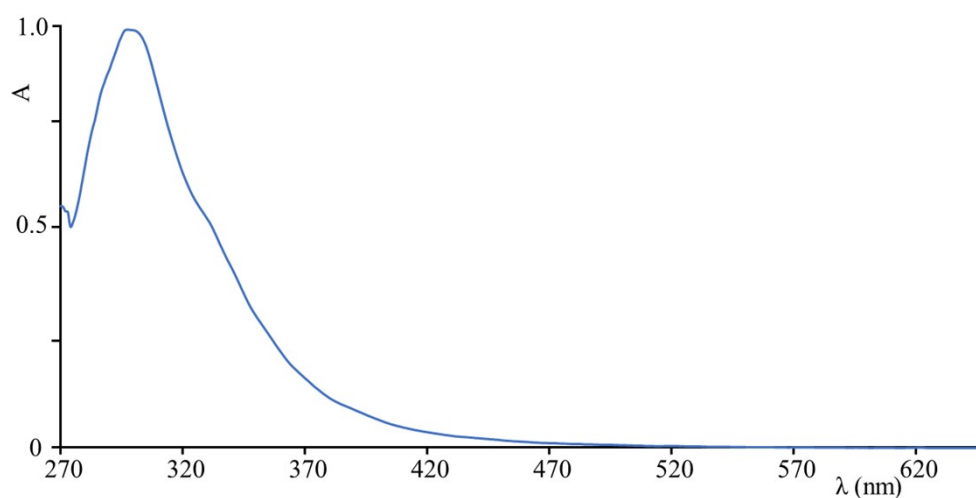


Figure S3. Absorption spectrum of LSC C-Dots system. The LSC had been prepared by using C-Dots at concentration 18 $\mu\text{g}/\text{mL}$.

Characterization of C-Dots via SEM

The samples were investigated through SEM analysis with a Zeiss Merlin M II, an electron microscope with high resolution scanning (capable of resolution secondary electron imaging with a resolution of 0.8 nm at 15KV and 1.4 nm at 1 kV with InLens secondary electron detector) at the acceleration voltage of 10Kv (EHT), 123pA. A drop of the C-Dots solution was placed in a sample stub 12,7 mm in diameter (product code RS-MN-10-003012), and dried under fume hood for 1 hour. Finally, the samples were sputter coated with gold-palladium foil for 120 seconds at 30 mA (milliamperes) and inserted in the SEM vacuum chamber. The original image (**Fig. S4**) was elaborated with Zeiss Zen Image Analyzer software.

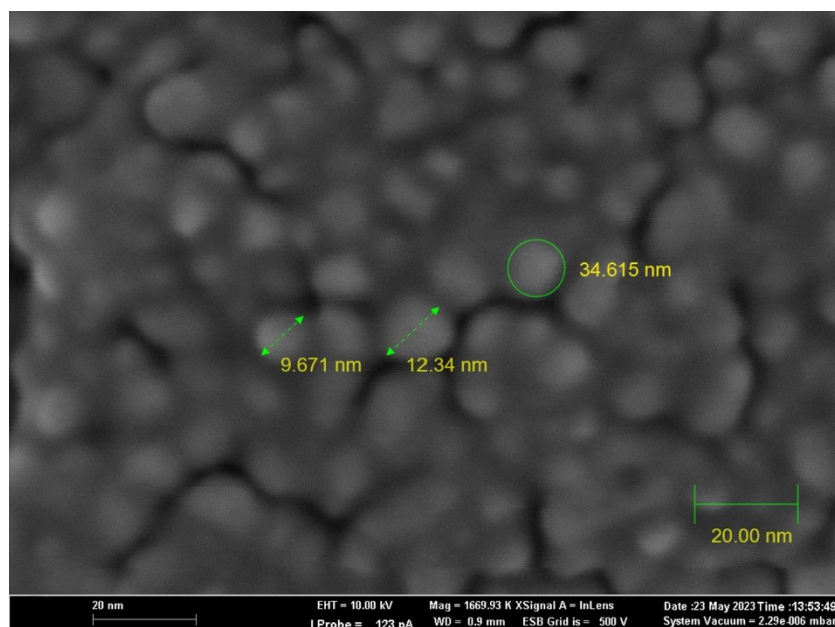


Figure S4. SEM image of C-Dots. The dashed double arrows indicate the diameter of the C-Dots nanoparticles; 34.615 nm refers to the circumference of a C-Dot nanoparticle, taken as example.

Excitation spectra

As already known for the C-Dots, the absorption spectrum in the UV-Vis region contains various contributions from many possible transitions, which can be related to particles of different size or to different portions of particles having same size. Keeping this in mind, the excitation spectra show more than one band as responsible for the emissions, and changing the emission wavelength, the ratio

among these bands changes.^{2,3} Analogously to the emission properties, the excitation spectra are not significantly different comparing C-Dots in solution and in LSC. Some examples are shown in **Figure S5**. below.

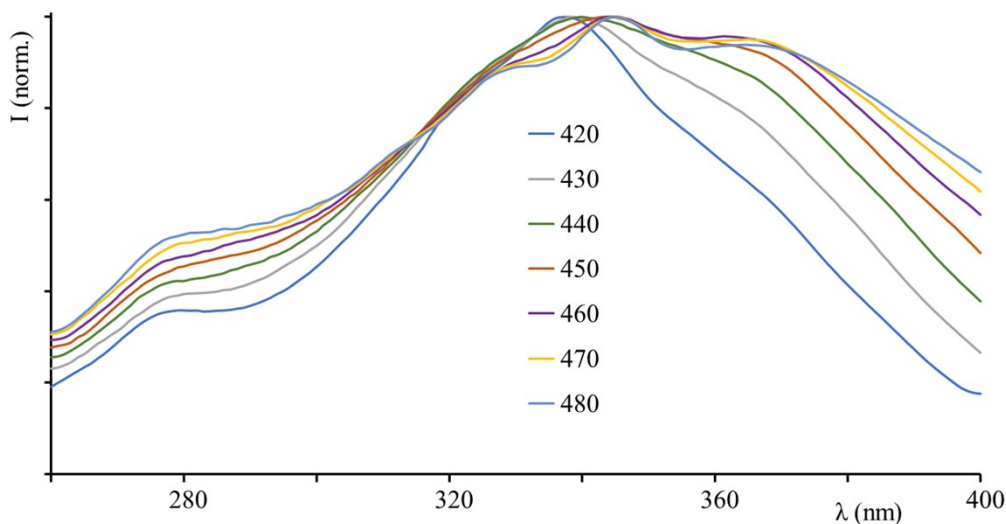


Figure S5. Excitation spectra of LSC C-Dots, at different emission wavelengths.

Fabrication of LSC

The luminescent solar concentrators had been prepared by thermal polymerization using lauryl methacrylate (LMA) as monomer, ethyl glycol dimethacrylate (EGDM) as cross-linking agent, and lauroyl peroxide as initiator. The ratio of these components was: LMA 65% w/w; EGDM 35% w/w; lauroyl peroxide 0.65% w/w with respect to LMA. Important: LMA and EGDM had been purified with basic activated alumina before the polymerization reaction.^{4,5}

The monomer LMA was heated to 80°C stirring under air condition. When the temperature was stable, the initiator lauroyl peroxide had been added, in order to start a pre-polymerization process. After 30 minutes, the temperature was cooled, keep stirring, and the cross-linking agent EGDM was added. To prepare the LSC C-Dots, 300 μ L of the C-Dots in dichloromethane solution had been dried under vacuum and re-dispersed by adding the liquid mixture above described. Then, the reaction mixture was left in ultrasonic bath for 10 minutes, to make it more homogeneous and remove any

pre-formed polymer. The final solution was introduced into a “home made” stamp, composed by two glass plates separated by a teflon stamp and clamped together. The polymerization occurred by placing this mixture in an oven at 90°C for 40 minutes. The so-obtained slab was then treated by sanding the surface and the edges to remove the roughness and to make the LSC smoother. ⁶ By following this procedure, we prepared four LSCs of same dimensions and containing the same concentration of C-Dots.

Photoluminescence and current as a function of the optical path

The dependence of the photo-current and of the luminescence by the optical path had been investigated using a spot laser at $\lambda = 406$ nm was used as monochromatic irradiation source, which was kept stationary, while the LSC was placed on a platform which allowed to move the LSC, so to control the position of the laser spot on the slab surface even of few millimeters.

To measure the emission spectra, the LSC was placed on the platform with one of the edges oriented towards an optical fiber connected to a spectrometer Ocean Optics USB2000.

To quantify the short-circuit current intensity, measured with a digital multimeter Agilent 34401A, one edge of the LSC was put in direct contact with the PV cell (Polycrystalline silicon photovoltaic panels $V_{oc} = 0.55$ V, $I_{sc} = 100$ mA), leaving the other edges uncovered.

The pictures showing the results of these experiments are shown in the main text.

Photovoltaic performance

The photovoltaic characterization of the LSC-PV device had been performed by irradiating the LSC perpendicularly using a solar simulator, which consisted in a Xenon lamp with an AM 1.5 Global filter, which can generate UV-vis light with the power intensity of 1 Sun (100 mW cm^{-2}). ⁷ The LSC was placed in direct contact with the PV cell. In order to reduce the interferences from reflected,

scattered and diffused light we covered the photovoltaic panel with a black stripe, leaving uncovered only a small region necessary for the contact LSC-PV (photovoltaic) panel. So, in this way, exclusively the light guided by the LSC is responsible for the photocurrent detected. The other 3 edges of the LSC were left uncovered, but this is taken into account in the G factor calculation.

The photovoltaic measurements had been performed on four LSCs of same dimensions and containing the same concentrations of C-Dots.

The G-factor was calculated using Eq. 2 mentioned in the main text and repeated here for convenience: ⁸

$$G = \frac{A_{top}}{2A_{edge\ long} + 2A_{edge\ short}} = \quad \text{Eq. S1}$$

where L and l are the long and the short side of the slab respectively, and t is the thickness. The values are reported in the **Table S1** for the blank and LSC C-Dots used.

Table S1. Sizes of the sides of the slab, expressed in cm²; the calculated G factor according to **Eq. S1**; and the area of the LSC in contact with the PV cell.

LSC	L (cm)	l (cm)	t (cm)	G factor	Contact area (cm ²)
Blank	1.90	1.83	0.36	1.29	0.66
C-Dot	1.92	1.67	0.33	1.35	0.54

The short-circuit current density of LSC C-Dot (J_{LSC}) was obtained by dividing the current intensity with the LSC/PV cell contact area which is indicated in **Table S1**.

While the short-circuit current density of the PV cell was calculated by dividing the current intensity of the PV cell under direct illumination by AM 1.5 G with the exposed area of the cell (See **Table S2** below).

Table S2. Photovoltaic data related to the photovoltaic cell under direct illumination by the AM 1.5 solar simulator.

I_{PV} (mA)	Area PV (cm ²)	J_{PV} (mA/cm ²)
4.65 (± 0.01)	0.94 (± 0.01)	4.95 (± 0.05)

Photostability

To test the photostability of the LSC C-Dots, the device had been irradiated perpendicularly using an AM 1.5G solar simulator at 100 mW cm^{-2} for 24h. The solar simulator was the same one adopted to measure the photovoltaic performance: a Xenon lamp with an AM 1.5 Global filter, which can generate UV-vis light with the power intensity of 100 mW cm^{-2} . The emission spectra had been registered quite frequently (exciting at 400 nm) and showed an intensity decrease occurred after the first hours of irradiation, but then the system appears enough stable over the time. The results are shown in the main text.

Solar spectrum absorption by LSC C-Dots

To measure the fraction of photons absorbed, an optical fiber connected to a spectrometer Ocean Optics USB2000 was used. The solar spectrum (black curve, shown in Fig. S6) was measured in the range from 370 nm to 1050 nm, using a solar simulator, consisting in a Xenon lamp with an AM 1.5 Global filter, generating UV-vis light with the power intensity of 1 Sun (100 mW cm^{-2}). The blue curve in Fig. S6 was obtained by subtracting the spectrum of the solar simulator lessened by the LSC (not shown in Fig. S6) to the solar spectrum (the black spectrum of Fig. S6).

The fraction of photons absorbed by the LSC (either blank or with the C-Dots) had been calculated by dividing the area of the the blue spectrum in Fig. S6 with the area of the solar spectrum in the range from 370 nm to 1050 nm.

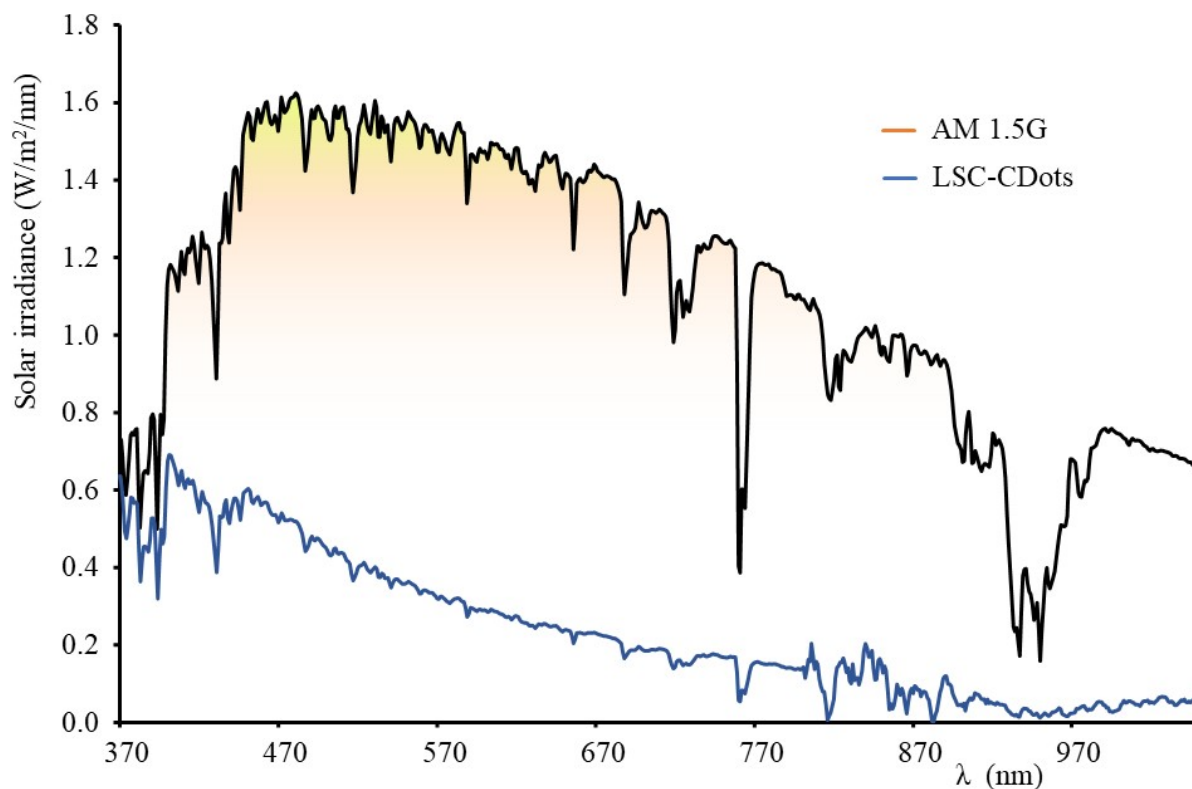


Figure S6. Solar spectrum using the AM 1.5G filter (in black) and the fraction absorbed by the LSC-CDots:25.16% considering that about 14% is the contribution of the rigid matrix (see full paper).

J-V curve measurements

The Voltage-current characteristic had been measured by using the solar simulator mentioned above in the text and a Keythley 236 source measure unit. The curve of the photovoltaic (PV) panel had been measured by placing the panel perpendicular to the irradiation source (as this is the same position adopted during the experiment including the LSC). The fill factor of the PV cell is 0.59, while is 0.64 for the LSC-PV device.

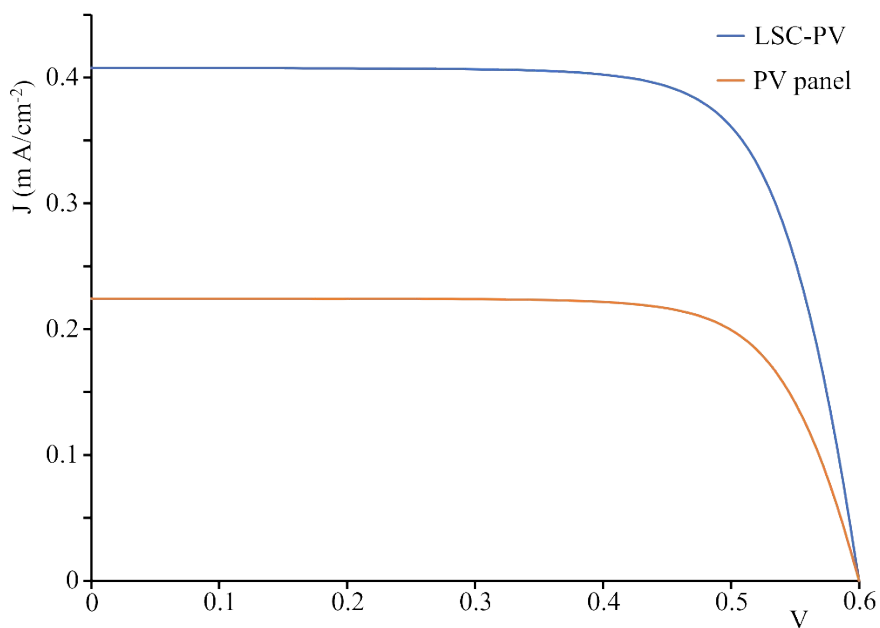


Figure S7. In blue, the J-V curve of the LSC-CDots coupled to the photovoltaic panel; in orange, the J-V curve of the photovoltaic panel, without the LSC.

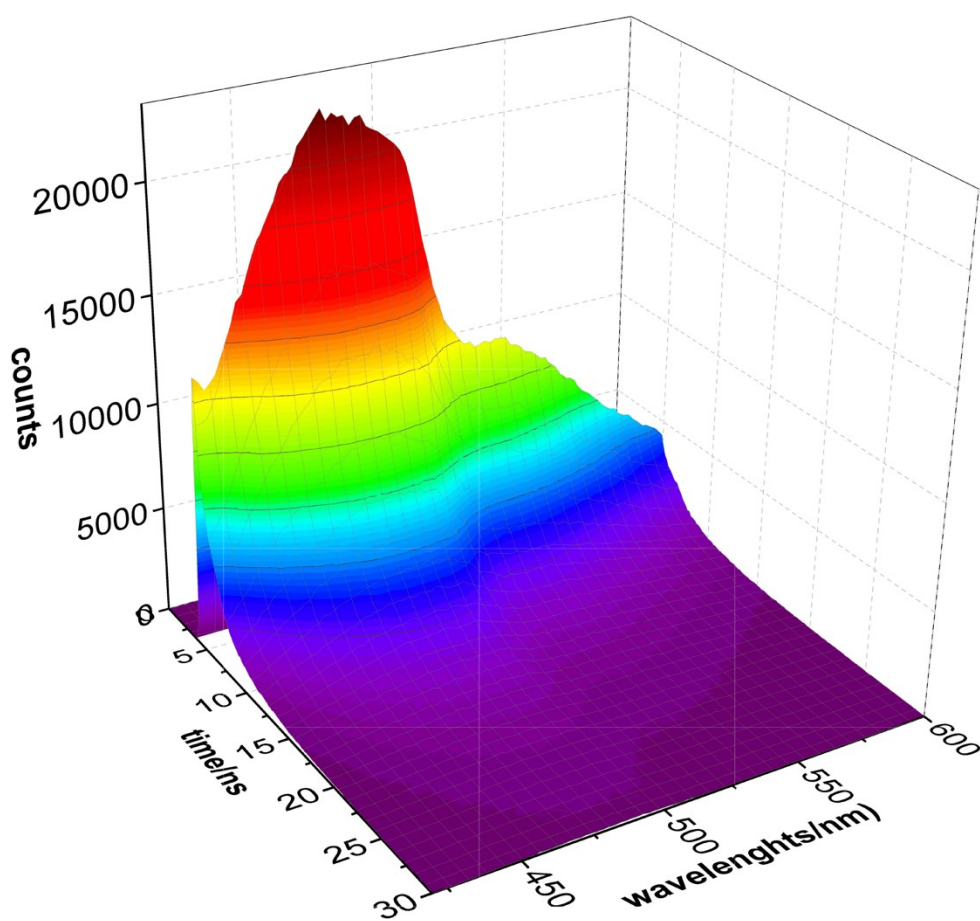


Figure S8. TRES matrix registered for CDots in DCM solution. Accumulation time: 100 seconds; excitation source Hamamatsu PLP 2 laser diode (59 ps pulse width at 408 nm).

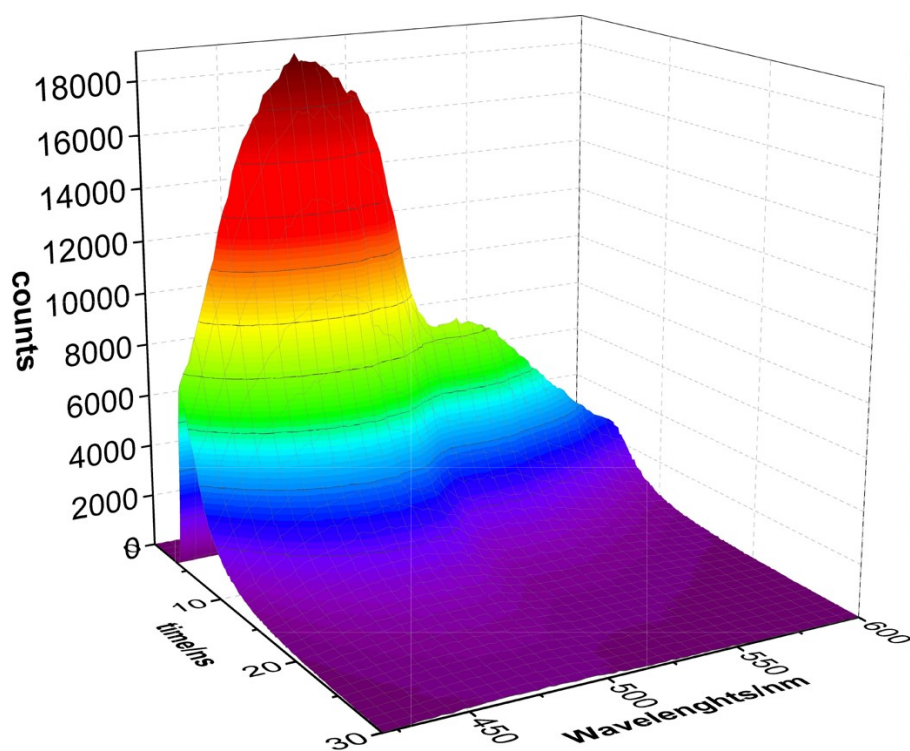


Figure S9. TRES matrix registered for LSC slab. Accumulation time: 100 seconds; excitation source Hamamatsu PLP 2 laser diode (59 ps pulse width at 408 nm).

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