Fluorescent-based Cool Materials- Recent Developments

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Different generations of cool materials

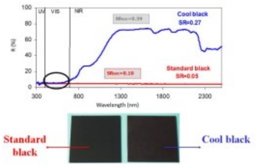
First Generation

Light-coloured cool materials

- Glare & aesthetic
- Limited application for roofs of high-rise buildings

Second Generation

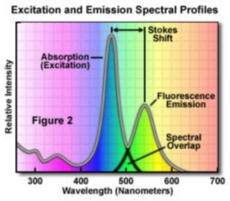
NIR-reflective cool materials



- Limited cooling potential
- Reflection only in NIR-range

Third Generation

Fluorescent-based cool materials (Bulk & Nano-scale)



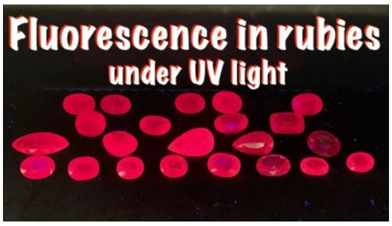
- Preserve colour
- Re-emission in visible range.
- Possibility for the integration of nano-scale fluorescent materials with NIR-reflective materials.

Fluorescent Cooling

Fluorescent Cooling/photoluminescence (PL) effect:
Fluorescent cooling refers to radiative/non-thermal relaxation of the absorbed light.

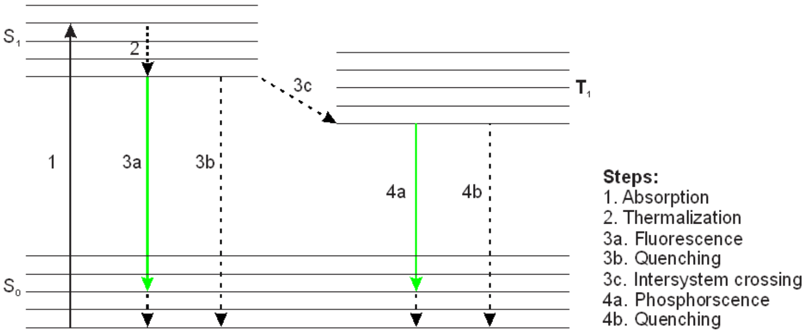
Fluorescent materials categorization:

1. Conventional bulk fluorescent materials (e.g. ruby) with fixed fluorescent properties and limited/certain heat-rejection potential.
2. Nano-scale fluorescent materials (e.g. Quantum Dots (QDs-Nano-scale semiconductor materials) (Tuneable fluorescent properties & possibility for integration with NIR-reflective materials).



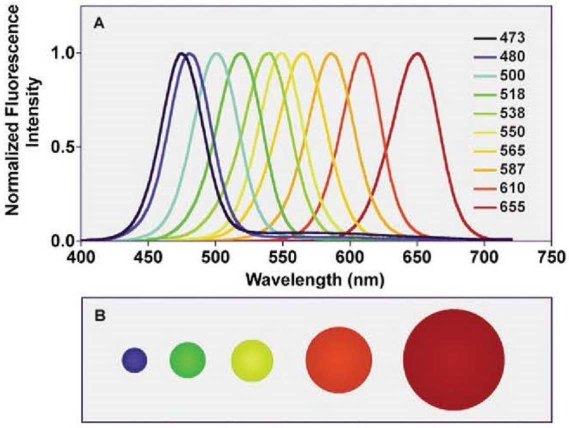
Quantum Dots

Fluorescent effect refers to the radiative/non-thermal relaxation of excited electrons. The fluorescent cooling effect occurs for the incident light having an energy level equal or higher than the QDs bandgap energy.



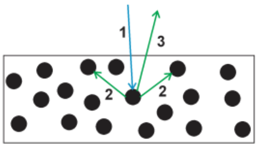
Fluorescent Cooling

❖ Absorption edge wavelength:
The wavelength with an energy level of bandgap energy is known as absorption edge wavelength (λ_{AE}).

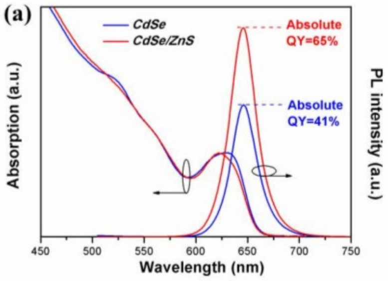


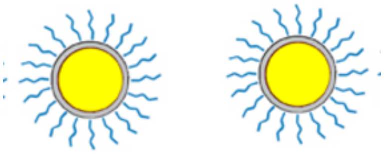
Quantum Dots

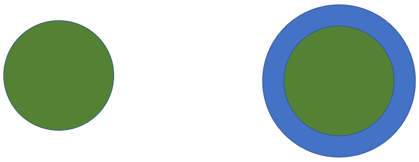
❖ Quantum yield, defined by the number of reemitted photons divided by the number of absorbed photons, could be adjusted by modifying the interparticle distance and surface chemistry modifications.



Interaction of light with QDs nanoparticles: (1) Light enters from the top surface and is absorbed by the QDs nanoparticles, (2) Light is reabsorbed by another QDs nanoparticle, (3) Light reemitted from the top surface.





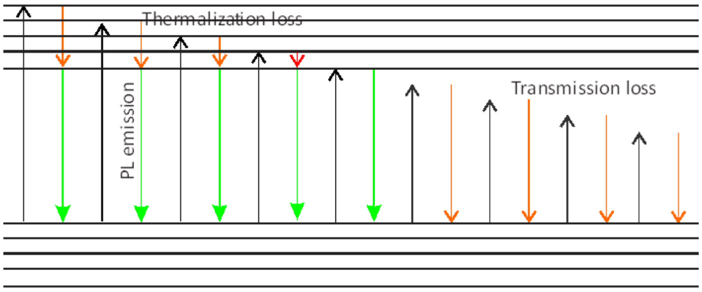


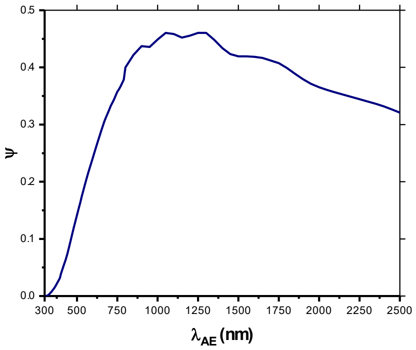
Core Quantum Dots Core-Shell Quantum Dots

Quantum Dots

Cooling potential theoretical limit

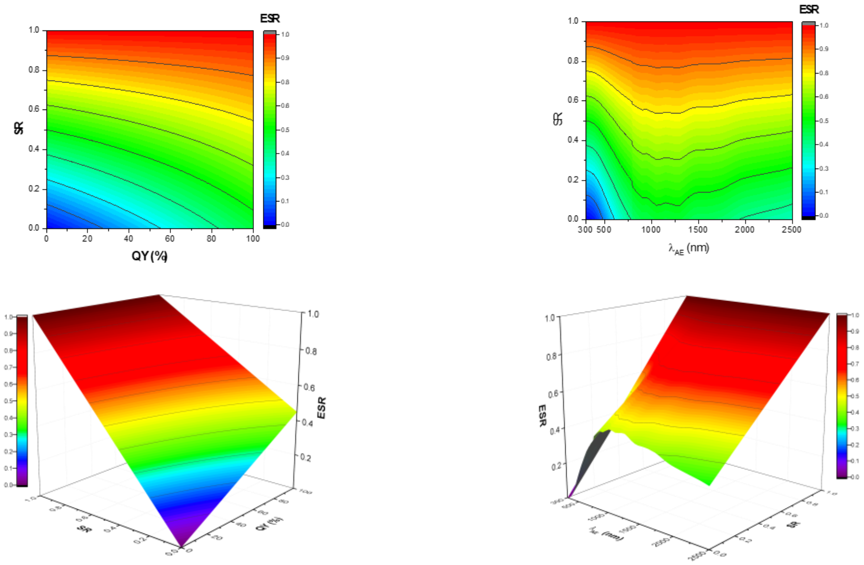
The fluorescent cooling theoretical limit is 0.15, 0.21, 0.23, 0.27, 0.43 for blue-emitting, green-emitting, yellow-emitting, orange-emitting, and red-emitting fluorescent materials, respectively.





Correlation between ψ and λ_{AE} for conventional Stokes-shift fluorescent materials

Optimization: Re-emitted energy through photoluminescence(PL) effect



Top left: Correlation between ESR, SR, and QY, contour plot. Top right: Correlation between ESR, SR, and λAE, contour plot. Bottom left: Correlation between ESR, SR, and QY, 3D plot. Bottom right: Correlation between ESR, SR, and λAE, 3D plot.

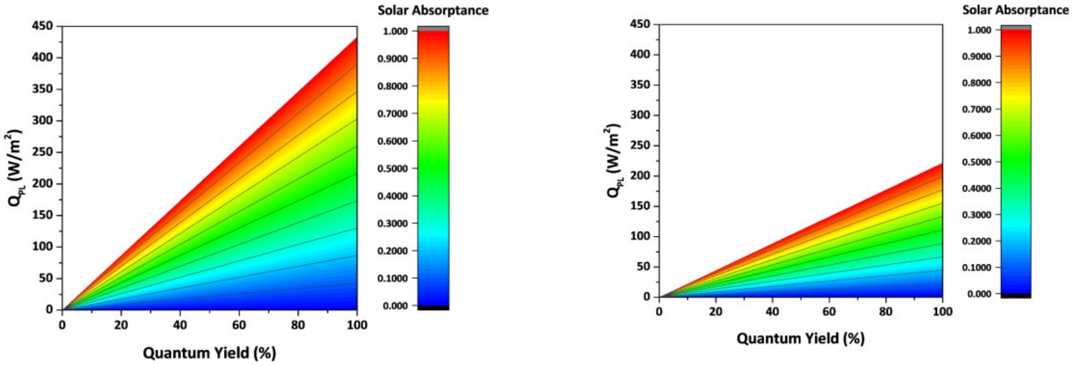
Optimization: Re-emitted energy through photoluminescence(PL) effect

Correlation between Re-emitted Energy (Q_{PL}), Solar Absorptance, and Quantum Yield(QY) in a representative summer day in Observatory Hill Station, Sydney

❖Absorption Edge Wavelength($\lambda_{Absorption\ Edge}$): 1000 nm

❖Average Solar Irradiation: 878 kWh/m2 during summer & 449 kWh/m2 during winter.

❖Maximum Re-emitted Energy through photoluminescence : 433 kWh/m2 during summer & 221 kWh/m2 during winter (49% of the incoming solar irradiation)



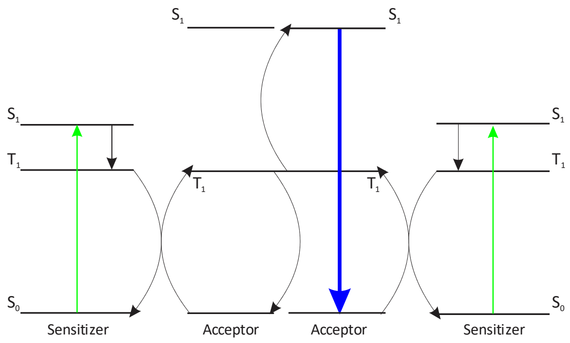
Optimization: Re-emitted energy through photoluminescence(PL) effect

The transmission and thermalization losses determine the theoretical limit for fluorescent cooling potential

❖**Transmission Loss:**

1. Up conversion of two photons with energies lower than the bandgap energy into one higher than the bandgap energy photon.

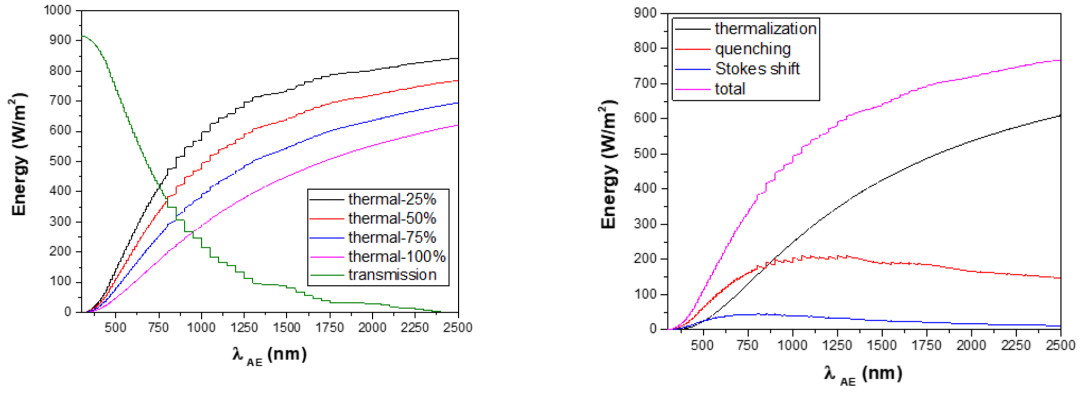
2. Transmission loss can be minimized through application of a NIR-reflective material as base layer.



❖ **Thermalization Loss:**
Down conversion of one high energy photon into two lower energy photons.

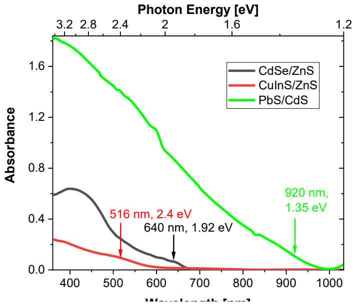
❖ **Quenching Loss:**
1.Reducing reabsorption by application of surface ligands around QDs core,
2. Controlling surface defects.

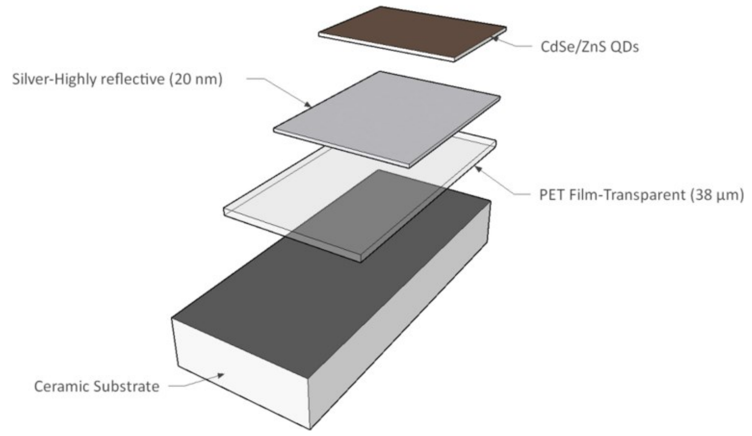
Optimization: Re-emitted energy through photoluminescence(PL) effect

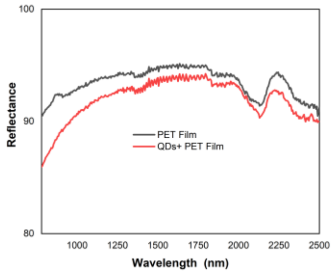


Left: Impact of λAE on thermal and transmission losses in Stokes shift fluorescent materials.
Right: Impact of λAE on thermal losses in Stokes shift fluorescent materials

Reducing transmission loss through integration with NIR-reflective materials







S. Garshasbi, S. Huang, J. Valenta, M. Santamouris, "On the combination of quantum dots with near-infrared reflective base coats to maximize their urban overheating mitigation potential", Solar Energy, 2020, 211, 111-116, https://doi.org/10.1016/j.solener.2020.09.069