13 March 2019

Feedback to the 1st Oeko Clarification Questionnaire on the OSRAM Exemption Renewal Request for the use of Cadmium in Quantum Dot LEDs for Display applications.

Renewal Request to renew Exemption 39(a) *under Annex III of the RoHS Directive 2011/65/EU:*

Cadmium selenide in downshifting cadmium-based semi-conductor nanocrystal quantum dots for use in display lighting applications (< 0,2 µg Cd per mm2 of display screen area)

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1. Your request is made to allow the use of cadmium in quantum dots “directly deposited on LED chips”. This suggests that an exemption is no longer needed for other Cd QD configurations, namely on-surface (QD light converting film) and on-edge applications.

We understand "on-surface" and "on-edge" as described in our request fig. 2 on p. 8.

OSRAMs approach is to concentrate the quantum dots close to the chip resulting in an overall lower total amount of quantum dots compared to on-surface and on-edge configurations.

Within the configuration “on-chip” two sub cases depending on the concrete application can be distinguished:

> *a) the dots are used close to the chip, around it, confined by the dimensions of an LED package, or*
>
> *b) the quantum dots are highly concentrated in a thin layer on top of the chip whereas this layer has got similar outer dimensions as the chip, i.e. smaller as the package.*

First products with this technology will soon be launched in the lighting sector.

a. Please confirm that it is your intention to exclude such Cd QD configurations from future RoHS exemptions for quantum dot applications.

OSRAM is not working with applications using large QD light converting films or tubes as described in your question. We see advantages in the newly developed on-chip configuration for lighting as well as for innovative display and projection applications which are only possible with on-chip configuration.

OSRAM cannot judge the necessity of these films or tubes with respect to other display applications (e.g. TVs, Computer displays).

Therefore we do not want to “exclude” configurations as listed in your question.

b. As it can be understood from the application that on-surface configurations were still applied in displays on the market in 2017, please explain how the market has changed in this respect.

OSRAM is not targeting displays as on the market today where these films with a higher Cd content is needed for gamut and efficiency. We do not have information about use of on-surface and on-edge configurations in the respective market.

We currently develop "on-chip" technologies that will need less Cd as foreseeable for innovative applications such as µ-displays, VR-glasses, BLU (on-chip converted LED for Back Light Unit) etc. For these innovative applications films or tubes cannot satisfy the requirements.

c. Please state whether the on-edge and on-surface configurations are applicable to lighting technologies.

In general it is technically possible to use on-edge or on-surface technologies for general lighting in order to realize flat area light sources. However we see substantial disadvantages today for this kind of usage e.g. coloured areas in off-state which might be unacceptable to customers as well as unpredictable high costs due to the application of the colour converting QDs over large areas. Therefore we do not believe these configurations will be used for lighting in foreseeable future. OSRAM is currently not working on such solutions.

2. It is explained that due to miniaturization, "the amount of converter needed is extremely low, i.e. the amount of cadmium is very low - much lower as the use of conventional converter material". A comparison of the amount of Cd needed for different configurations of Cd QD used in a 55" display is provided in Figure 2, however without specification for the on-chip configuration.

a. Please provide an estimated range for this case, explaining how the quantum efficiency influences the amount of Cd and what this translates to in terms of the display properties.

The higher the quantum efficiency of the Cd containing converter material, the lower the needed amount of Cd. The display energy consumption will be lower respectively.

We estimate that significantly less than 1 mg Cd would be needed for one 55" TV when directly converted LEDs were used.

Converter solution	**ppm Cd in Cd-containing material**	**µg Cadmium per LED package**	**µg Cd per 55" TV screen (240 LED type "5630" per TV**
Green emitting phosphor + Red QD	170	0,68	163
Green QD + red QD (highest efficiency)	435	1,7	408
Green QD + red emitting phosphor	300	1,2	288

Please see the table above for LED builds using "5630" packages for white BLU (back light unit) LED packages.

We are comparing 3 different converter solutions replacing either the red emitting phosphor or the green emitting phosphor or both phosphors (highest efficiency).

b. If the other configurations (on-edge, on-surface, but also the technology for which LightingEurope has requested an exemption - see question 6) are applicable to lighting technologies, please provide a comparison of the amount of Cd needed for a few examples of solid state lighting (SSL) products.

As stated in 1c. OSRAM does not see "on-edge" or "on-surface" technology for lighting developed in the near future; only the "on-chip" technology for which Lighting Europe has requested an exemption is the applicable technology for lighting. In the latter case one would use ~10µg per 100 lm-LED. This corresponds to < 1000 ppm in the Cd-containing material as described in the request.

3. How does the technology for which the exemption is requested compare to other CdQD configurations in terms of energy consumption and in terms of other relevant performance parameters (e.g., colour gamut in displays, colour output and warmth of SSL, etc.). Please explain aside from Cd content if the technology in focus has other advantages over existing Cd QD configurations.

For general lighting a higher efficiency by up to + 20% is expected at comparable CCT and CRI values compared to best available non CdQD phosphors. See also table below in question 5b.

For on-chip configuration in display backlighting efficiency and colour gamut will be the same compared to "on-surface" and “on-edge”, however, the amount of Cadmium is reduced dramatically.

In addition, OSRAM sees innovative technologies and applications that cannot be addressed today as explained in our request p. 9. The only possible realization of the necessary degree of miniaturization needs the use of CdQD in on-chip configuration. The miniaturization comes along with an overall reduced material consumption.

4. Please explain what conventional light technologies still on the market (discharge lamps of different types) “Cadmium in downshifting semiconductor nanocrystal quantum dots directly deposited on LED chips” is expected to replace and provide comparisons of the technologies to allow understanding the advantages in terms of energy consumption, light quality and colour, etc.

Display: Hg-containing discharge lamps are since quite some years no longer in use for displays. They are only required as spare parts for special industrial, commercial or medical displays.

Solid State Lighting: LED packages are electronic components used in LED lamps and LED luminaires and other equipment. So the LED package alone cannot replace a lamp or a luminaire. But it can be used in lamps and luminaires replacing phosphor based LED packages. As the energy efficiency is significantly higher we globally expect a faster transition from discharge lamps to SSL if the market (producers of lamps, luminaires and other equipment offering light) accepts the technology including higher prices which will be expected due to higher production costs.

5. OSRAM explains that "The highly innovative technology needs further research and development for the LED itself but also for existing and new applications where the components are intended to be".

a. Is it correct to understand that Cd QDs are not yet applied in on-chip configurations in products available on the EU market?

This is partly correct. The answer is yes for backlighting in displays. The research and development in this direction is ongoing and first results are very promising.

This is different for SSL: OSRAM Opto Semiconductors is currectly planning to release 90 CRI OSCONIQ products in May 2019, which utilize Cd-based QD materials at a level below 100 ppm Cd and are definitively compliant with current ROHS regulations. These could easily be modified to realize much higher efficiency gains (up to 3 times higher, see table in question 5b) as soon as an exemption is granted.

b. What stages are still foreseen before actual products can be expected to come onto the market - please detail for each stage what needs to be performed and provide an expected timetable for completion.

General Lighting products with on-chip technology (RoHS conform, <100 ppm Cd) are technically ready and fulfill all requirements with respect to performance and quality. Currently, we are ramping up production. Please understand that we cannot communicate details of our marketing strategy or time planning for public market introduction.

In the next step we are able to release within short time LED for general lighting with even higher efficiencies. These LEDs will contain < 1000 ppm Cd and therefore have to rely on the exemption requested by LightingEurope. As soon as the request is granted, this product can be released. Test data from first prototypes can be provided within the next months.

3000K CRI 90 0,2W LED	**Phosphor-only LED (best in class)**	**CdQD LED 2019**	**based on this exemption - CdQD LED**
Cd content	0 ppm	< 100 ppm	<1000 ppm
Luminous efficacy	reference	+7%	+20%
Energy consumption	reference	-7%	-20%

Applications for display backlighting and µ-displays are developed in parallel and require the exemption for Cadmium per mm² light emitting LED chip surface. But the future development efforts on such innovative materials and applications are also dependent on the renewal of this exemption (with the proposed new wording). First products for such applications can be expected in 1-2 years.

Current work is mainly focused on improvement of reliability and chemical stability. Unfortunately we cannot provide more detailed information due to the confidentiality of the research.

For both applications, lighting and displays, the next steps are development of products by our customers. For lighting the LED have to be integrated in luminaires, for display applications probably even R&D work is required to develop and market the planned innovative products.

6. You mention the exemption request of LightingEurope for a new exemption for "cadmium in luminescent material for on-chip application on LED semiconductor chips (lighting)".

a. Please explain the difference between the two technologies;

The basic technology of Quantum Dots as wavelength converter to generate green or red light from the blue LED light is the same. In lighting, the mixture of conventional phosphors and Quantum Dot wavelength converters shall generate high-quality white light. Here only red QDs are required to enhance the emission spectrum of conventional phosphors (especially if high CRI is required)

In contrast, for display applications, spectrally narrow green and red light is needed for a high color gamut. In addition to fulfill the demanding optical requirements for a display system, the phosphor layer is typically much thinner and thus requires a very high weight percentage of Cd in that layer than used in the relatively thick layers in lighting applications.

For example:

For BLU green and red QDs are required. Narrow-band green increases efficiency (lm/W) dramatically. Today only red QD in combination with green phosphor is available, a situation which needs to be improved. For the innovative µ-display application red and green on-chip full conversion on tiny scale using very thin and highly concentrated QD-layers is technically necessary. For this new technology OSRAM sees the use of Cd-based QDs as essential, as described in our application form (p 9-10).

Therefore, for the display application we propose to limit the amount of Cd per mm^2 chip surface instead of using an extended ppm level like in the lighting application. This is the technical background for the different wordings proposed for the exemptions for lighting and displays.

b. Please specify if the two technologies could be addressed under one exemption and if so propose a suitable formulation (an exemption with two items, however with a common title is also an option in this respect), also referring to respective exemption durations.

Exemption valid today for displays:
Cadmium selenide in downshifting cadmium-based semiconductor nanocrystal quantum dots for use in display lighting applications (< 0,2 µg Cd per mm2 of display screen area)

OSRAM change proposal for displays:
Cadmium in downshifting semiconductor nanocrystal quantum dots directly deposited on LED chips for use in display and projection applications (< 5 µg Cd per mm² of light emitting LED chip surface).

LightingEurope exemption request for lighting:
Cadmium (<1000 ppm) in luminescent material for on-chip application on LED semiconductor chips for use in lighting applications of at least CRI 80.

We agree that it is possible to combine the exemptions for the use of Cadmium in QD under one exemption, split into different applications. As the display and projection application we are working on is not yet finally ready for the market the current exemption for Cd in QD LED could also be included into the wording depending on the argumentation of the renewal request mentioned in question 1, which is not known to us.

The exemptions could read:

Cadmium in downshifting semiconductor nanocrystal quantum dots

- *directly deposited on LED semiconductor chips for use in display and projection applications (< 5 µg Cd per mm² of light emitting LED chip surface)*
- *directly deposited on LED semiconductor chips for use in lighting applications of at least CRI 80 (< 1.000 ppm in the luminescent material)*
- *not directly deposited on LED semiconductor chips for use in display and projection applications (< 0,2 µg Cd per mm² of display screen area)* *)

  Expires for all categories on 31 October 2024

*) OSRAM currently does not work on such on-edge and on-surface configurations.

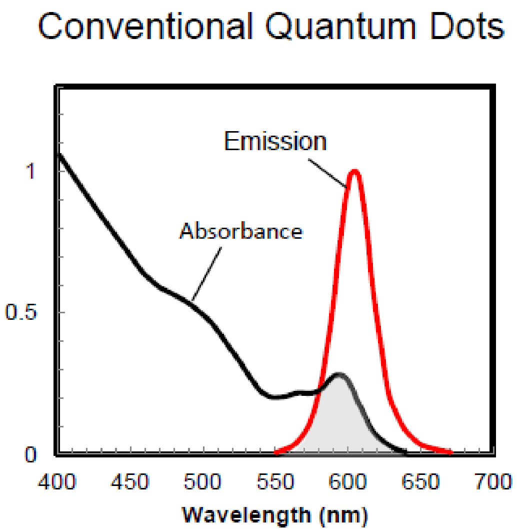
A duration of 5 years is required in order to allow products to be developed and marketed based on the electronic components we are preparing. A shorter period would be extremely negative for the acceptance of the technology on our customers side It would lead to legal uncertainty whether the effort they need to spend for products and applications leads to success. It would hamper innovative products offering advantages in terms of energy efficiency supporting the EU's energy savings and climate change agenda.

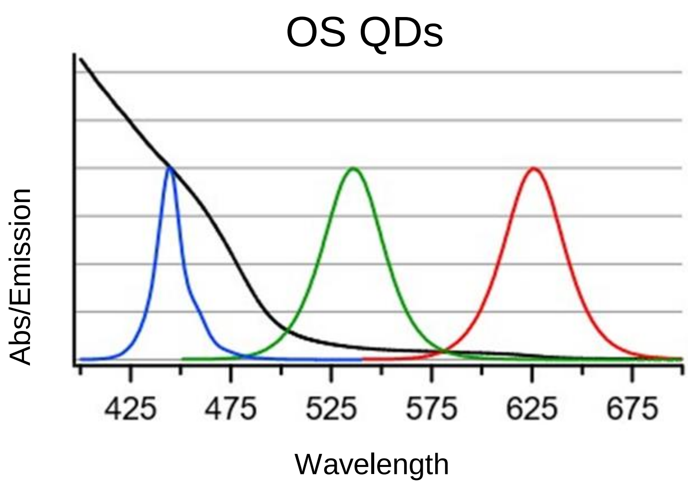
7. OSRAM states that "Cd- free quantum dots do not offer the same narrow spectra and they do not withstand the LED reliability requirements." Please provide a quantitative comparison between Cd based QDs and Cd-free ones, showing the differences in reliability performance of such technologies in the on-chip configuration.

Cd-free QD spectral width is in the 40nm range and above, while Cd QDs have FWHM <30nm; Cd-free quantum efficiency as measured under high temperature and high flux conditions is <50% while for Cd QDs under those same conditions it is >80%. There does not currently exist a Cd-free material/technology that can withstand the high flux and temperatures involved in the on-chip configuration. Benchmark testing of Cd-free QDs on chip has shown immediate loss of optical performance in minutes/few hours. OSRAM Cd-QDs under same standard backlighting LED test conditions can withstand >1000 hours as far as tested today.

8. Please provide a more detailed explanation as to the difference between "conventional QD" and "QD where absorption and emission are more separated by a different core-shell concept". Please refer in your answer to structural differences (the concept of a core shell system) as well as the properties of each type (re-absorption and concentration quenching effects) and how these influence the general performance of the QD in an application.

Typical absorption/emission shown below with core dominating both the emission and absorption characteristics (this is typical in InP based systems that the shell has negligible absorption regardless of thickness). On the right spectrum core shell structure has significant absorption by the shell (e.g. CdSe / CdS rod structure). The amount of absorption by the shell is tunable based on the ratio of shell thickness to core size. The spectral shape of the absorption is then determined by the shell material and can be chosen to minimize overlap with emission wavelength. Note the minimal overlap between absorption and emission for both the green and red emission peaks. This minimal spectral overlap dramatically reduces self-absorption and so minimizes concentration quenching effects. This enables reasonable efficiencies to be maintained for the working concentration needed for on chip LED operation. The CdSe/CdS core shell is the only system that can realize these benefits. See also exemption renewal application p.11-12.





9. Please provide an explanation/definition of what is meant by “µ-display”.

"µ-display" means a miniaturized display technology using a monolithic light emitting (III/V-) semiconductor chip consisting of a number of lateral semiconductor segments ("pixel"). All segments can be controlled in emission brightness individually by current sources directly connected to each pixel. The resulting pixel pattern in emission brightness ("image") is then projected on a screen or directly into the human eye. Respective applications are mobile video projection, automotive Head-Up-Displays (projection to wind screen), Virtual- or Augmented Reality glasses. In order to create full color images, the (blue) emission color of the semiconductor chip has to be locally converted for each pixel into other colors (green and red, see Fig 5 in the application, p.10)

10. In figure 3, please explain what “Si-carrier with CMOS array” means.

This means a Silicon-based integrated circuit (IC) manufactured in Complementary Metal Oxide Semiconductor (CMOS) technology, providing the pixel-related current sources mentioned in Question 9. Both, the III/V semiconductor segments and the current sources are arranged in a matrix-like pattern ("pixel array"). See also the following link:

https://www.osram.com/media/resource/HIRES/617159/1006156/flyer-bmbf-gb.pdf

List of abbreviations

BLU	on-chip converted LED for Back Light Unit
Cd	Cadmium
Cd QD	Cadmium Quantum Dot
LED	Light Emitting Diode
lm	Lumen
On-chip	Configurations in which downshifting semiconductor nanocrystal quantum dots are directly deposited on LED chips for use in various applications.
On-edge	Configurations in which downshifting semiconductor nanocrystal quantum dots are located in a light converting tube
On-surface	Configurations in which downshifting semiconductor nanocrystal quantum dots are deposited on a light converting film for use in various applications.
OSRAM	OSRAM GmbH, Munich and OSRAM Opto Semiconductor GmbH, Regensburg
SSL	Solid state lighting
VR	Virtual Reality