# Reply to Questionnaire Exemption Request No. 2013-2

## Exemption for Cadmium in II-VI LED Downconversion

### Questions and Answers

1. QD Vision explains that quantum dots are semiconductors whose electronic characteristics are closely related to the size and shape of the individual crystal. Furthermore, you state that quantum dots absorb blue light and re-emit the energy through fluorescence down-conversion at longer wavelengths in a very narrow band. The exemption request refers to a backlighting unit component that includes a material containing a colour converting II-VI semiconductor for LEDs and in a liquid crystal display (LCD) system.
    a. Please describe more precisely how the cadmium is used and bound in the quantum dot technology in respect of various areas of application for instance, in control films, glass tube, polymer matrix, core, shell or different quantum dots sizes etc. Please provide some detailed figures for each technology for a better understanding.

Quantum dot technology has several implementation methods and therefore some elements of difference, but it also has common features. In all cases, the QDs are made up of a core semiconductor which is overcoated by a shell semiconductor. The core semiconductor contains cadmium, primarily the II-VI semiconductor cadmium selenide. By changing the size of this cadmium selenide core the emission color of the material is tuned through the principals of quantum mechanics. The core cadmium selenide semiconductor is a near-perfect single crystal of several thousand atoms, where the precise number of atoms is determined during synthesis. The size and color are in this way determined during manufacturing of the QD material.

The QD core is then overcoated with one or more additional semiconductors during a second synthesis step in the manufacturing process. The overcoating material is inorganic semiconductor, typically zinc sulphide or the ternary alloy cadmium zinc sulphide. It is again a near-perfect crystalline layer (or epitaxial layer) grown atom by atom on the surface of the QD core. The shell is not necessarily uniform throughout, and might be graded such that it is cadmium rich near the core-shell interface, and zinc rich near the shell surface. The ligands are attached to the surface of the shell, and these are typically small organic molecules that bind to the shell surface, and present functionality to the solvation sphere that can be tailored by the selection of these molecules. There is a great variety of choice here, but these organic species do not contain any cadmium. Figure 1 (appended to this document) shows this core-shell-ligand quantum dot pictorially, as well as how core size determines color.

The next step of product integration in most cases will involve dispersing the QD (core-shell-ligand) into a polymer matrix. This can be acrylic, silicone, epoxy, and again the choices are almost limitless. The polymer may also contain other additives, both organic and/or inorganic. The polymer serves to space out the QDs so that layer thicknesses are more easily manufacturable, and also to bind the QDs into a solid mass, since a pure QD (core-shell-ligand) solid is better described typically as a waxy solid. Our published, peer-reviewed work (Liu et al.) has shown that the polymer also serves to diminish greatly or eliminate entirely leaching of QDs into a landfill or groundwater environment. The polymer matrix does not contain any cadmium other than what is in the QDs.

Figures 2-5 in the below show pictorially and photographically how this QD-in-polymer material can then be incorporated into various product forms. In lighting products, the polymer is a thin film layer (~100um) between two sheets of glass (~500um each), placed in front of an array of “mint-white” LEDs (Figure 2). The efficiency benefits of this product were significant and easy to quantify. The QD layer in this case contained only red QDs, as the green component was provided by conventional, rare-earth containing phosphor in the mint-white LED package.

Figure 3 shows what we consider to be the three viable geometries of QD inclusion into LCD backlights – on-chip, on-edge, and on-surface. Our peer-reviewed article (Coe-Sullivan et al.) describes the pros and cons of these geometries in some detail. In summary, at the time of this writing, there are no QD solutions that are capable of surviving in the on-chip environment, the on-edge geometry is implemented and on the market (world-wide including the EU), and the on-surface geometry seems to be rapidly approaching the market, with no products for sale to date. QD Vision today sells only the on-edge products and hence has the most information about this geometry. QD Vision is aware of a competitor currently marketing the on-surface geometry (3M, trade name QDEF or quantum dot enhancement film).

Figure 4 shows two depictions of the on-surface geometry. As QDs require some level of barrier protection from the oxygen and moisture in the air, two barrier film layers surround the QD layer. The QD layer is likely 50-100um thick, and may include some combination of polymers surrounding both the red and green QDs.

Figure 5 shows several images of our current product, the on-edge configuration that we market as Color IQ. 2013 TVs marketed in Europe under the Sony Bravia Triluminos moniker contain this product. The Color IQ optic is a hermetically sealed tube of glass – a tube of glass sealed with glass on both ends. The hollow portion of the tube is filled in with the QD-polymer material described above. In 2013 product, the tube was 4x2 mm in outside diameter (race-track shape, as shown in Figure 5a) and the inside layer thickness was ~700um. An entire 55” TV contains about 1-2mg of QD, which in turn is ~1mg of Cd. This is inclusive of both the red and green QDs found within, both of which separately contain cadmium. QD Vision believes this geometry is preferable because of its reduced packaging costs, materials costs, and material usage. We estimate that it has 10-100x less cadmium per display area than the on-surface type described above.

The on-chip variety is irrelevant at this time, since to our knowledge there are no QDs available that can survive under these operating conditions today. Over time this challenge is expected to be resolved, and with continued investment, the on-chip geometry should be available for low power, small display area applications, followed by high power applications such as TV in the more distant future.

b. Which areas of application are to be covered by the exemption - would this application range require a change of the proposed wording? If further applications are relevant for an exemption, would it be possible to formulate the wording so that a general exemption for cadmium in quantum dots is available to all relevant applications such as LCD devices and light illumination applications?

As we read the current exemption, we consider it to apply to the full range of products described above. They are all applications of II-VI downconversion material to LEDs.

We believe the current text is appropriate and workable. We do not believe that the text is overly broad, or exempts more applications than intended.

c. Are there other manufacturers besides QD Vision producing the mentioned types of applications?

As of this writing, there are no other manufacturers in the market. QD Vision expects, however, that 3M and Nanosys will be in the market by end of year 2013. There are other potential players within the industry, including Pacific Light Technologies, Merck KGaA, QLightNano, Navillum Technologies, NN Crystal, and Samsung. In addition, nearly a dozen potential consumer electronics companies appear to be considering 2014 product launches using this technology.

d. Please describe the emissions in all the life stages of Cadmium in II-VI LED through the production, use, and disposal or recycling of the LED?

Given the very early state of this technology in the market (it launched for the first time between our December application, and this writing) there is no quantitative data yet on the life cycle emissions. However, we can speak to this question generally, and in a forward looking manner.

There is no production in Europe, nor are we aware of any plans to start production in Europe. In production, QDs are produced in a quick, two-step wet chemical synthesis. The cadmium atomic yield in this process is very high (>90%), and the batch yield to usable product is also very high (>95%). This process is now well described in our recent article “Quantum Dot Manufacturing Requirements for the High Volume LCD Market” in the Society for Information Displays 2013 Proceedings, inclusive of representative manufacturing control charts.

Cadmium not yielded into QDs, and batches not yielded into product are disposed of as hazardous waste in compliance with strict US EPA Hazardous Waste Disposal regulations implementing the Resource Conservation and Recovery Act. The material is incinerated in a fuel blending plant in Texas. QD Vision is an ISO 14001 certified company. Our hazardous waste service provider is a Tier 1 vendor, and QD Vision routinely audits their process to ensure compliance with local, state, and federal environmental regulations. The component making process (QD → Color IQ optic) is similarly high yield, and any unyielded parts or polymer-QD matrix are managed as waste consistent with local disposal regulations in Taiwan where this fabrication process occurs.

In use phase, there are no emissions of cadmium – the cadmium is tetrahedrally bonded in a crystalline solid, embedded in polymer, hermetically sealed in glass. If the product (a TV) were to break in use phase, there is no conceivable way that there could be a cadmium emission.

In disposal phase given the covalent crystalline nature of the QD, there is no risk of gas phase emissions. All products containing the technology fall under the WEEE directive and are, therefore, subject to collection and recycling. Waste that is not recycled or recovered under WEEE would end up in a landfill or be incinerated. In landfills or products abandoned in nature our work in Liu et al. demonstrates that there is virtually no release of cadmium to the groundwater, and essentially zero emissions of QDs. For incineration the temperatures involved and the existing processes for purifying emissions would capture the Cadmium.

For WEEE that is recycled, QD Vision has performed preliminary work with recyclers in the EU confirming that the Color IQ components can be separated from the rest of the LCD panel, and have identified a viable end-use market for this separated waste stream. Existing processes within the EU for battery recycling are compatible with Color IQ components, and hence the waste generated can be re-used in this fashion.

For cadmium containing waste that is not separately recovered, the recycling process generally begins by removing the combustible material, such as plastics, with a gas-fired thermal oxidizer. The plant’s scrubber eliminates the polluting particles created by a burning process before releasing them into the atmosphere. The WEEE is then ground into very small particles. Non-metallic substances are burned off; leaving a black slag on top that a slag arm removes. The alloys settle according to weight and are skimmed off like cream from raw milk while in liquid form.

Cadmium is relatively light and vaporizes at high temperatures. In a process that appears like a pan of water boiling over, a fan blows the cadmium vapor into a large tube cooled with water mist, and the vapors condense to produce cadmium that is 99.95 percent pure. The world’s largest metals recycling company, Umicore, indicated that it had processes for treating cadmium WEEE waste that are environmentally responsible and that the only risk of exposure was for workers during the recycling process. Workers are fully protected and are required to wear personal clothing and equipment to abate any risk of exposure. As cadmium recycling already takes place regardless, together with the very modest amount our technology will add to the waste stream, there is no incremental risk.

2. You claim that possible substitutes are OLEDs, RGB LEDs, CFQDs.
    a. Please provide a comparison of LCDs based on traditional LEDs with more absorptive colour filters, hybrid LED, or wide colour gamut white LEDs with respect to aspects such as energy consumption through the product lifetime, use of hazardous materials, performance aspects of products and other aspects that are important for establishing why alternatives are impractical or why they are inferior to the application for which the exemption has been requested?

We provided the comparisons to OLEDs and RGB LEDs since these two solutions can be currently found, in limited instances and with worse environmental performance, in the market. The comparison to CFQDs was important since they are the obvious, direct substitution, were they to become available – which we also believe will have worse overall environmental performance despite not having cadmium in the product.

The three additional alternatives inquired after are not to our knowledge in the market, but nonetheless could be at some point in the time window of relevance. Traditional LEDs with more absorptive color filters could potentially achieve the same color performance as QDs, but with the massive trade-off that one is absorbing photons and converting them to heat rather than just generating useful photons with a QD. Thus, the power efficiency of such a device would be worse than a QD solution, by at least several 10's of percent. Not only would one need to absorb the 'edges' of the color spectrum to achieve the color improvement, but because of the absorptive slope of all known absorptive materials, this would simultaneously reduce the magnitude of the transmission peak, further reducing the useful photons out of the front of the device. To our knowledge, no such color filters are now on the market, and hence quantifying this efficiency loss is difficult, but an estimate of a 50% loss is reasonable. For the reasons already described in the application, this 2x reduction in efficiency is far worse for the environment, even solely looking at cadmium introduction, than the equivalent QD display. The technology to implement this solution has existed for some time but has not been introduced to the market due to its severe limitations in performance, cost, and environmental effect.

'Hybrid LED' is a term that has been applied to many technology development efforts, none of which are a viable alternative for commercial, high color gamut displays or lighting products.

Wide color gamut (>100% NTSC) white LEDs again do not exist on the market, nor are we aware of a credible source of such technology. The phosphors to achieve this level of performance do not exist, though there are some materials that can approach 80-90% of NTSC. This approach could then be combined with the more absorptive color filters described above, but again this would be connected with a large reduction in efficiency that would result in a solution with overall poorer environmental performance. QD Vision has evaluated the best known narrowband emitting phosphors available on the market, and the performance of these materials is inferior to that achieved with QDs.

b. Are there alternative semiconducting materials that can replace the cadmium-containing semiconducting material in the II-VI LED, for instance zinc oxide as semiconductor?

Today there are no alternative semiconductor materials that can replace the cadmium in II-VI downconversion materials and retain sufficient performance to be useful. Indeed, the search for cadmium-free semiconductor QDs has been on-going for a decade or more, and the best (but insufficient) known candidate today is indium phosphide, a III-V semiconductor. This material as a potential alternative is already well described in the application under CFQDs.

Focusing on other II-VI materials, one is left with the semiconductors of zinc and the alkaline-earth metals. The alkaline earth metals (Be, Mg, Ca, Sr, Ba) in general form very wide bandgap semiconductors, and hence would not result in visible emitting QDs. They are either not relevant for this reason or very poorly explored in the literature and hence not suitable for replacement on a relevant timeframe. The zinc semiconductors have received thorough exploration in the literature. Similarly, ZnO and ZnS are wide band gap and hence not useful as visible emitting materials. ZnSe, ZnTe, and ZnSeTe have lower bandgaps that allow one to access the blue end of the visible spectrum with QDs, but none can be made into efficient emitters in the green or red, where all QD downconversion products must emit.

It is possible to dope emitting ions into any of the higher bandgap semiconductors mentioned here and elsewhere, and hence make a doped QD without cadmium in it. We emphasize, however, that the bandwidth of emission of these materials is quite wide, and hence this material class has very little value as an alternative to QDs, but is rather an alternative to conventional phosphor if it were to some day mature into something commercially viable in terms of efficiency and reliability.

3. Do you agree that Cadmium in II-VI LED enables a reduction of the total cadmium amount used in traditional LEDs and LCD? If yes please provide supporting information.

When viewed from a net life cycle perspective, we agree with this statement. Our application makes all the arguments about cadmium release as a byproduct of electricity production, and shows the math that supports this net reduction of cadmium being output to the environment. The information provided above and below about cadmium recycling further supports that, despite the different life cycle stage in which the cadmium is potentially introduced into the environment, the cadmium capture percentage is extremely high regardless of stage.

4. You stated that OLED are the only possible substitute in the near future that can achieve 100% NTSC colour gamut. Whereas the RoHS Directive bans the use of cadmium since 2006 and there are no comparative products on the EU market.
   a. Do you agree that articles using II-VI semiconductor downconversion materials are from an environmental, health and / or consumer safety point of view, suited to replace existing fluorescent lamps or conventional LEDs used in RoHS-

relevant applications, i.e., exhibit a better performance concerning these aspects?

Yes, we would agree with these statements. Our 2010 product with Nexxus lighting showed that for applications where remote downconversion lighting is acceptable (flood beams vs narrow spot lights) the narrow band emission of a red-emitting QD can yield significant (20-40% compared to conventional phosphor based LED) efficiency benefit that far outweighs the small quantity of cadmium that the part contains. The comparison to fluorescent lamps is even easier to make, since these products contain mercury, also a RoHS substance, and in a form that is in our opinion somewhat less safe for the consumer.

The reason these QD-based lighting products have not gained great market acceptance is related to 1) cost, 2) design limitation of the remote downconversion plates, 3) lack of performance in the on-chip geometry which is dominant in the LED lighting industry, and 4) lack of focus, since there are no QD companies dedicated to putting these products on the market, in part because of the regulatory environment.

b. Please explain in more detail, why OLED in comparison to applications using II-VI semiconductor downconversion materials currently do not provide the same performance or energy efficiency.

These analyses are extremely complex, and hence there is no analysis that QD Vision can provide here to which an expert of contrary opinion couldn't find fault. First, any analysis would have to segment lighting from displays, since the comparisons and metrics of relevance are quite different for each. In lighting, white OLEDs are much discussed, and currently always face a significant efficiency deficit compared to LEDs with or without QDs [see for example DOE report referenced in the application]. This deficit is projected to continue, and the best forecasts are clear that this gap will never close.

In displays, the analysis is quite complex, since the energy consumption of an OLED display depends on the image that is being displayed. In applications where the screen is black, an OLED consumes almost no power, whereas an LCD consumes as much power as when displaying a white screen. Adding complexity, local dimming LCDs can actually turn off the LEDs where the screen is black, offsetting this benefit. Comparing white screens, most LCDs are more efficient than most OLEDs, but of course this isn't truly a relevant operating condition either. The diversity of LCD options (4K vs 2K, VA vs IPS, back vs side illuminated, etc) makes choosing the right comparison arbitrary, and subject to bias. Overall, it is telling that OLED smartphones are almost always run at ~60% of the brightness of an LCD – this is in no doubt in part because of the higher power consumption and shorter lifetimes of OLED devices, but is also in part because of the higher perceived brightness of the more saturated OLED colors.

c. What display sizes cannot yet be manufactured with OLED? Is it possible to use OLED and applications using II-VI semiconductor downconversion materials in the same applications (can they replace one another), for instance in the small-size displays?

OLED is today shipping in great volumes into smartphones (with Samsung as the sole provider), and in units of 100's into the TV market (Samsung and LG). One reason that no company other than Samsung is shipping smartphone displays is because many others have tried and failed to get the manufacturing process working sufficiently. In TVs, similar issues have meant that the yields are reportedly very low [see for example http://www.forbes.com/sites/markrogowsky/2013/07/28/oled-finally-arrives-but-is-the-dream-tv-really-worth-it/ for a very recent article on the challenges] and hence the TVs are well over $10k and cannot be produced in great volumes. Given the trajectory of LED backlit LCD, it seems unlikely that these OLED displays will be more energy efficient than LCD when they do finally come to market.

In theory it is quite possible for OLED and QD-based LCD to be used in the same markets. Today, OLED is largely found in small areas only, and today QD displays are only found in TVs, so there is essentially no overlap (only the few hundred OLED TVs shipped thus far in 2013). We do expect this to change, as OLEDs get larger (perhaps tablets next, rather than TVs), and QD displays smaller (using either on-edge or on-surface products). We expect that as the market segments being to overlap, it will be even more apparent that QD enhanced LCDs consume less power than OLEDs for most display situations.

5. The OLED production is relatively new, however in the consultants view already established on the market, whereas applications using II-VI semiconductor downconversion materials are currently not available on the EU market.

Sony TVs using II-VI semiconductor downconversion materials are on the market in the EU as of this writing. See for example: http://www.sony.de/product/tv-102-40-lcd/kdl-40w905a for a series of three Sony televisions on sale in Germany (and throughout the EU and the world). This is a recent development, first being offered for sale this spring.

a. Please elaborate what stages are necessary and which efforts will be made to develop II-VI semiconductor downconversion material based displays with sufficient reliability.

Sony TVs using II-VI semiconductor downconversion materials are on the market in the EU, and hence already have the reliability to be in mainstream displays. While further improvements are possible, there remain no stages necessary to achieve sufficient reliability. This is perhaps in contrast to OLEDs, where "The models on display in Harrods showed some signs of burn-in after just a few months on the floor." [Forbes reference, above]

b. Why do you think that this target may be achieved earlier with II-VI semiconductor downconversion material technology than with the OLED technology?

Sufficient reliability targets were achieved for II-VI semiconductor downconversion materials in 2013 TV products. OLEDs still may not have achieved this goal, and certainly do not have the manufacturing yields and capacity to ship more than a few hundred TVs in 2013.

Reliability targets are perhaps easier to achieve in QDs than in OLEDs because the QDs are operating in downconversion mode only, and do not pass charge through the emitting material. Our own work on electroluminescent QDs (QLEDs) show that passing current, rather than maintaining charge neutral materials, severely decreases the reliability of a typical luminescent material as it opens up many new degradation mechanisms not otherwise present.

c. Aren't there products / applications with shorter periods for re-design?

LED products, such as consumer electronic devices with displays and lighting devices, typically have a relatively short redesign cycle of from six months to two years. However, most of these redesigns are at the level of industrial design, software, or electronics. Redesign that involves materials is typically on a much slower cycle, often measured better in decades. QDs, for example, were first made in the late 1980's, were seen as a promising material for displays in the early 1990's, and saw first display market introduction in 2013. OLEDs were similarly discovered in the late 1980's, saw intense research in the 1990's, and didn't achieve significant display market adoption until the late 2000's. The pace of discovery around conventional phosphor materials is even slower, as these materials were under intense research even prior to 1900 (e.g. Edison and Braun) and saw significant market adoption in the 1930's and 1940's.

6. Even if WEEE (Waste Electrical and Electronic Equipment Directive 2002/96/EC) were collected separately and submitted to recycling processes, its content of cadmium would be likely to pose risks to health or the environment especially when treated in less than optimal conditions.

We refer to our answer above that cadmium is already recycled in very large quantities also from WEEE and that according to publicly available information this can be done safely. We refer in this case to statements made, for example, by Umicore which is the technology leader in this area. If the statement implies that the cadmium in the QD technologies poses a risk outside of recycling we do not concur as the cadmium is bound in the solid matrix in such a way that it cannot lead to exposure.

a. Could you please elaborate more in detail, the (existing) efforts which have been made to establish a closed-loop business-to business return system? Please provide evidence in more detail

Years ahead of the need for such recycling systems to be in place, QD Vision has engaged in setting up such systems in the EU proactively. QD Vision products on the market in the EU are rated for 30,000 hours of operating life, and only some 1000-2000 total hours have elapsed since the products were first offered for sale in the EU.

Since QD Vision does not have an internal employee who is truly expert in emplacing recycling systems, we have hired a third-party consultant who is expert on these matters. This third-party expert has been under contract starting in 2012, and has prior experience in particular with the battery and plastic bottle industries in setting up both open and closed loop recycling systems, both in the US and the EU. He has executed multiple trips to the EU on our behalf to meet with over a dozen participants in the EU recycling supply chain, including those functioning in the separation of WEEE and LCDs in particular, those who have potential end-use markets for our materials, and those with unique processes that can separate not just at the mechanical component level but also those who can perform chemical separations of the metals in our materials. We have sent development scale samples of components for testing at multiple sites to see which existing processes and end-use markets might be applicable to the future waste stream generated. One can imagine the difficulty of this task, started before the first products were on the market, and indeed many years before such a waste stream might exist for processing.

To date, we have confirmed that the mechanical separation of the QD-containing components is feasible. Furthermore, we have identified one end-use market as being able to consume the QD-based waste in their existing processes. We are continuing to seek others, as one market may be better than others in terms of cost, or other logistics (local to the generating point).

Finally, we have identified a potential vendor that may be able to provide us with a true closed-loop recycling solution. The vendor is in the process of generating a proposal for developing this process, but it is something that we are eager to understand better and explore. This vendor claims extensive experience in developing such processes for the battery industry, and has experience that spans both academia and industry.

b. Please explain what happens to the cadmium which cannot be recycled.

According to sources the recycling rate is >99.95% and the remaining waste is treated as hazardous materials so that it can be disposed of safely. Based on the US EPA standardized Toxicity Characteristic Leaching Procedure (TCLP) testing that we have conducted, no cadmium (undetectable to ppb levels) is released under the testing conditions. This allows us to conclude that the vast majority of cadmium that ends up in the landfill remains within the polymer binder of the product and does not enter the environment as cadmium. In addition, we have studied (Liu et al.) what might happen under harsher testing conditions, and have confirmed that while these conditions release a small fraction of the cadmium contained in the material, all of the cadmium is in the ionic form, where the ecological and environmental effects are relatively well known. In the case of incineration of the products the temperatures involved gasify the cadmium which is then captured in the normal filtering process of such facilities. There is neither added cost nor added risk due to the QD technologies. Given the total quantities involved in this exemption application, the proactive approach we are taking to recycling, and the low rate of cadmium leaching determined by both standardized and uniquely developed experiments, the potential negative environmental impact is negligible, and the net benefit that might be accomplished via energy efficiency increases far outweigh this potential negative.

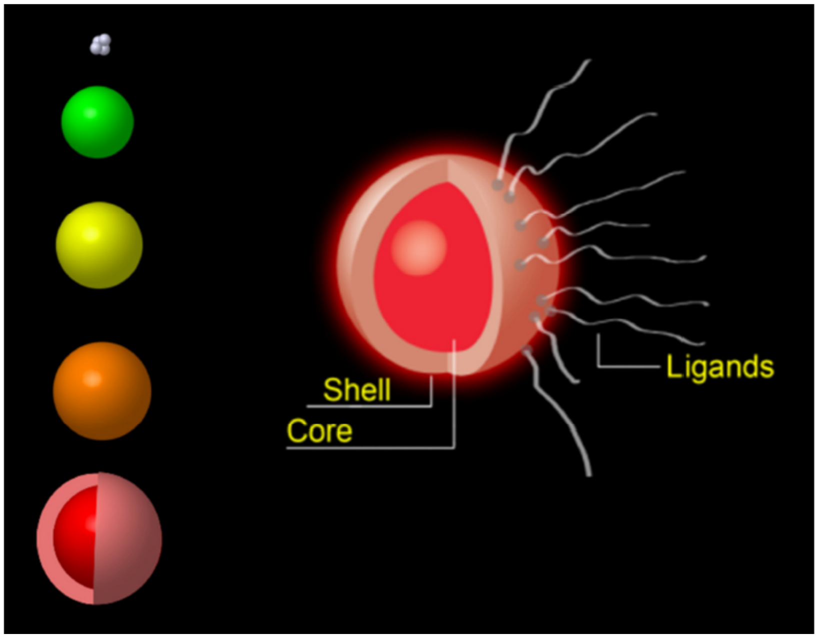


Figure 1: Quantum Dot core-shell-ligand structure. Series of spheres to the left depicts emission color is a function of core diameter.

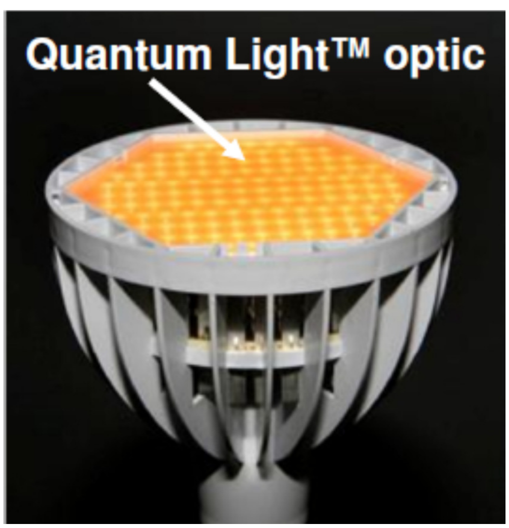


Figure 2: Quantum dots in remote lighting configuration. Photograph of lightbulb product marketed in 2009 – 2011, which had performance of 2700K (Kelvin), >90 CRI (color rendering index), and over 60 lm/W (lumens per electrical Watt), roughly 50% better efficiency than the next best available Led product on the market at the time.

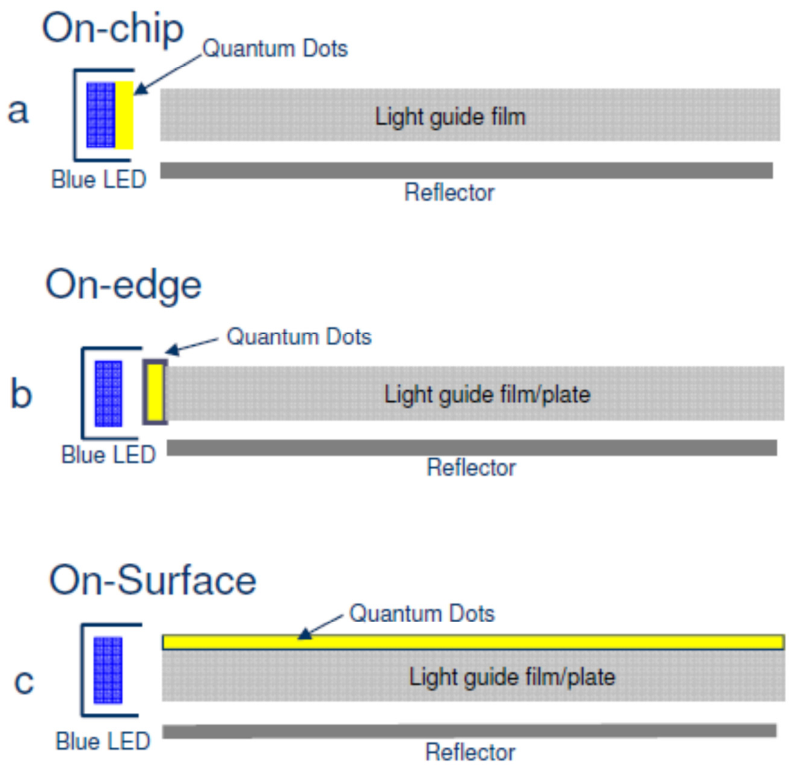


Figure 3: Geometry comparison of three different implementation methods for quantum dot use within a liquid crystal display back light unit (LCD BLU). Figure 3a shows the QDs placed within the LED package, an implementation not currently practicable. Figure 3b shows the on-edge implementation found in several models of TVs currently on the EU market. Figure 3c shows the on-surface or film implementation, currently being offered for sale and expected to appear on the market in the coming year.

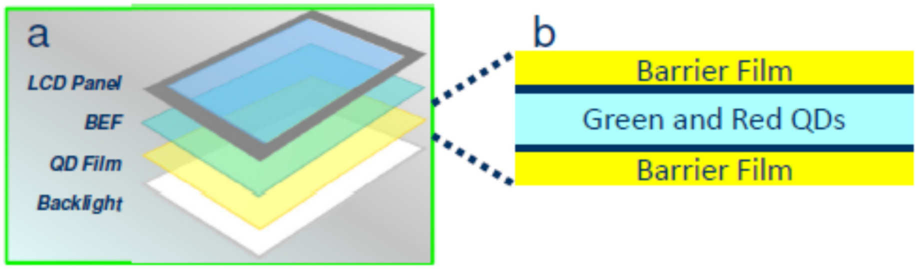


Figure 4 depicts the on-surface implementation of QDs within an LCD BLU in greater detail. 4a shows one option for how the film is located within the existing LCD BLU film stack. Figure 4b shows greater detail of the QD film, which is likely comprised of a film of red and green QDs sandwiched between two barrier film sheets to provide the QDs with protection from oxygen and water vapor.

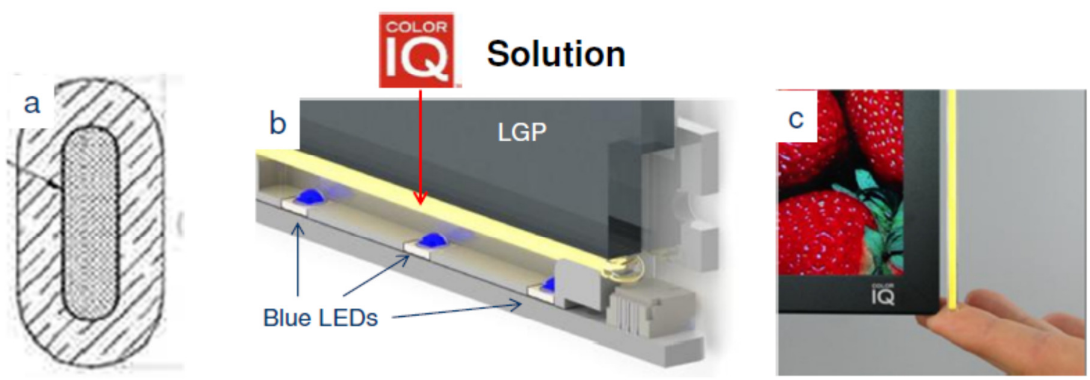


Figure 5 shows several views of the on-edge implementation of QDs within an LCD BLU in greater detail. 5a shows a cross-section of the glass tube, where the grey area in the center contains the QD-polymer mixture and the hashed perimeter is glass with exterior dimensions of ~4mm by ~2mm. Figure 5b depicts an angular view of LCD BLU teardown, demonstrating the relative configuration of blue LEDs, QD optic (Color IQ), and light guide plate (LGP) that one would find on one or more edges of a large-area television. Figure 1c shows a TV in operation, with a separate QD optic held in proximity to the edge of the TV set to illustrate the relative dimensions and locations of TV and optic.