Peter Palomaki: The Evolution of Quantum Dot Technology

This is Part II of our quantum dots series with nanotechnologist Peter Palomaki, Ph.D., owner and chief scientist at Palomaki Consulting, explores the evolution of quantum dots technology, looking at it might move past using sheets to dots-on-chip and electroluminescence and how scientists could overcome the current roadblocks to implementing these innovations.

If you haven't seen Part I, you can read it here.

What are different options for implementing QD technology in displays?

There are different ways of how quantum dots can be implemented within a display.

Quantum dot film (current QLED)

Quantum dot film will remain the form factor of choice in TVs for the immediate future. This method is easy to implement, relatively cost-effective, has many benefits and is becoming a mature technology.

Quantum dot color filters

This will likely be the next step. However, it's still unclear whether this will be with a blue LED backlight unit, an OLED backlight unit, or both.

Some of the benefits of using color filters are improved efficiency and viewing angles. This implementation can potentially reduce component costs, TV weight, and thickness too. However, this technology is unlikely to be available for at least a couple of years.

Quantum dots on-chip

This is where quantum dots would replace phosphor technology. Existing LEDs have a phosphor mixed in with silicon on top of the blue LED, converting it to the white light. Replacing the phosphor material with QDs would mean directly converting that blue light to pure reds and greens instead.

Quantum dots on LED chips is an even greater technical challenge than quantum dot color filters because of the high temperature, high light flux, and oxygen that the quantum dots would be exposed to, causing their rapid degradation. Because of this, quantum dots need to be specifically engineered to survive in this environment.

Although the technology has been commercialized for mid-power LED lighting, there are currently no quantum dot materials that can survive high-power LED packages. Researchers are still working on overcoming the on-chip challenge for displays.

It's possible that the use of quantum dots on LED chips won't be achieved because using quantum dots in color filters will become commercialized faster. If color filters are successful, some benefits would be lost if the technology returned to the back of the screen.

Both technologies have benefits and are being actively researched so we will see demos of both in the coming years at display conferences. However, it's still unclear whether either technology will mature enough to be implemented in consumer displays.

Quantum dot electroluminescence (EL)

Electroluminescent quantum dots encompass all the benefits of the above technologies – high efficiency, high color quality, great viewing angle and the potential to be printed on a flexible substrate.

If realized, this will be the new standard for display technology. Its commercialization would be as influential as the advent of LED and LCD. If successful, it will likely eliminate LCD.

However, there are large challenges to implementation at this point. Within this form factor, quantum dots are electrically stimulated. Once electrons and holes recombine after this stimulation, they emit a photon of light of a specific color, which is dictated by the size and composition of the quantum dot.

When you use quantum dots in this way, they are even more susceptible to damage than when you use them as a down converter, because now they are the LED itself. There is no LED in a typical sense anymore. It's now a quantum dot LED. The function is exactly the same as a normal LED, but instead of using a monolithic semiconductor, you are using a layer of quantum dots as the semiconductor.

In the research setting, people are showing that red electroluminescent quantum dots devices can be fairly stable. We are talking 10,000s of hours. Green devices are less stable, on the order of 100s of hours. Blue quantum dot electroluminescent devices are even less stable with only about dozen hours.

While this approach is not ready to be commercialized yet due to the stability of the materials, it can be done, from a technical standpoint.

The challenges are great, but the benefits are even greater, potentially. This is why there is a lot of research in this area. If this research is successful, we will see major changes to the display industry.

How does the implementation of quantum dots in TVs compare to using the technology for digital signage?

With digital signage and large area displays, many use individual LEDs for each pixel or sub-pixel. The implementation of quantum dots here would be very different from how you would integrate them into an LCD panel.

For LED digital signage, quantum dots would need to be implemented onto the LED itself – which as we discussed is not a currently available form factor. As always, there is the additional challenge of high temperature and high light flux when placing quantum dots directly onto an LED.

The challenges of incorporating quantum dots into LEDs for larger area displays are significant. This is a challenge that the industry is trying to find a solution for.

What are the technical roadblocks you envision in the near future and what are some ways in which researchers and companies may tackle these?

Electroluminescence

Due to their small size, quantum dots have a lot of surface area. This can cause degradation, defects, and artefacts that cause inefficiencies.

For electroluminescence, there are also other manufacturing challenges, such as needing to pattern at the sub-pixel level. We know how to do this using lithography and can possibly do this using inkjet printing in the future. However, it's going to take complex electronic components to drive individual sub-pixels independently.

The advancement of OLED TVs will help the development of electroluminescence quantum dot technology because they share a lot of the same challenges. Electroluminescence can lean on and learn from the OLED community as these devices mature. However, it will still take innovations that are currently unforeseeable.

Stability

One of the original issues for quantum dots was their stability. This affects all quantum dots, and not just electroluminescence.

Inside a TV, quantum dots are in a harsh environment of relatively high temperature, high light flux, and exposure to the atmosphere. Historically, quantum dots would degrade quickly in these conditions and TVs would change color rapidly.

This was obviously not acceptable for commercialization. However, the technology has massively improved in the last five years. In its current form factor as a film on the back of the TV, there is very little concern about the degradation of the material.

However, as the industry matures and improves newer form factors, the issue may return and require different solutions. This is something the industry is already taking action on. The big problem has been solved for the current generation, but it is going to need to be resolved again for future generation quantum dot displays.

Thickness of quantum dot film

Quantum dots have the potential to be utilized for smartphone screens but the limiting factor is the thickness of the quantum dot film that is used in TVs.

The film appears no thicker than a piece of paper but this is still too thick for a cell phone. There needs to be a different form factor for quantum dots to enter the mobile market.

However, improvements to quantum dots technology may allow it to enter the mobile market and complete with OLED. There are new methods of implementation that are not yet mature that will improve quantum dots in displays overall and address the mobile market.

Toxicity

Traditional quantum dot material contains cadmium, which is known to be a toxic element.

People are now making different types of quantum dot materials to reduce toxicity. All Samsung QLED TVs contain the popular alternative indium phosphide. This material does not contain cadmium so is presumably less toxic and therefore more acceptable by governing bodies and consumers.

Companies are continuing to further research new materials that contain no toxic elements but give the same benefit of cadmium-based quantum dots.

There are many options out there that are early in early research stages or adoption cycles, such as non-lead-containing perovskite, which emits a very narrow wavelength of light that gives pure color. Other materials being investigated include silicon, which although widely-used in modern electronics, has weaker optical qualities, and indium gallium nitride, which is used in the semiconductor industry to make blue LEDs but has not yet been made into quantum dots.

This is the second part of a three-part series looking at quantum dots. Sign up for our newsletter to get Part III: MicroLEDs and Quantum Dots.

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