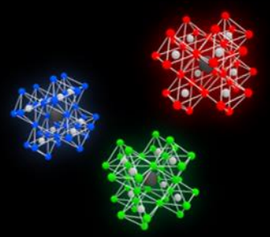
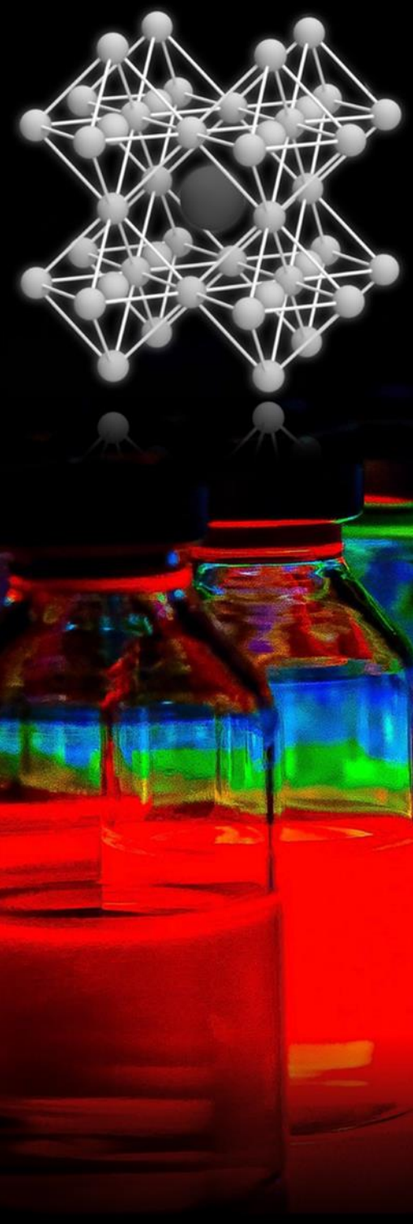
Perovskite Quantum Dots

Next-generated Innovation with Fusion of Iodine and Organic Electronics





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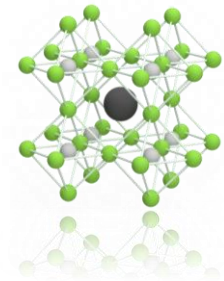
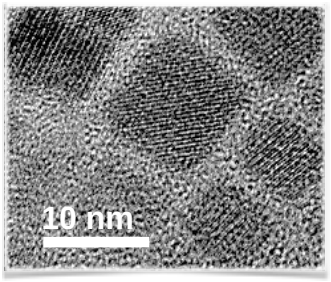
山形大学 Yamagata University

FROM

What is “Perovskite Quantum Dot (PeQD)” ?

PeQD = Next Generation Opto-Electrical Material



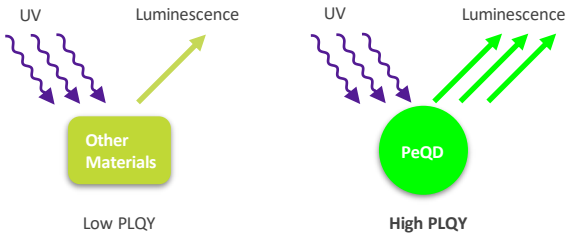


PeQD is an advanced material that is made by microfabricating perovskite semiconductors. Its shape is a very small particle equipped with a ligand, about 10,000 times thinner than a human hair. It is attracting attention as a next-generation light-emitting material with high PLQY, high color purity, and high color adjustability.

Perovskite quantum dot (PeQD) is an optoelectronic material consisting of perovskite crystals of about 10 nm and ligands adsorbed on the PeQD surface. PeQD is an ABX_3-type ionic crystal, consisting of organic or alkyl metal cations (methylammonium (MA^+), formamidinium (FA^+), Cs^+, etc.) as A sites, transition element ions (Pb^{2+}, Sn^{2+}, etc.) as B sites, halogen ions (Cl^-, Br^-, I^-) as the X sites.

- High PLQY

※ PLQY = Photoluminescence quantum yield

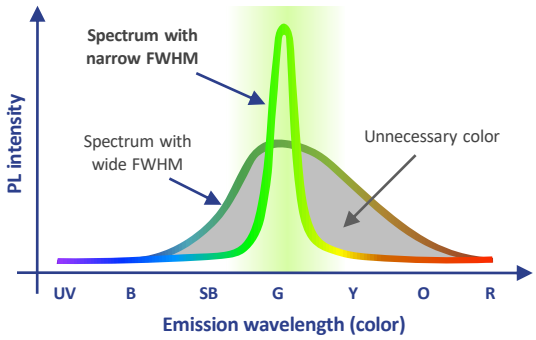


Possible to convert the UV light to specific light.

Light-emitting materials such as PeQD absorb light unique to each material, convert the wavelength, and emit light. In particular, PeQD has extremely high light conversion efficiency and can achieve a luminescence quantum yield (PLQY) of 100%, which is an indicator of conversion efficiency.

- High color purity with narrow FWHM

※ FWHM = Full width at half maximum

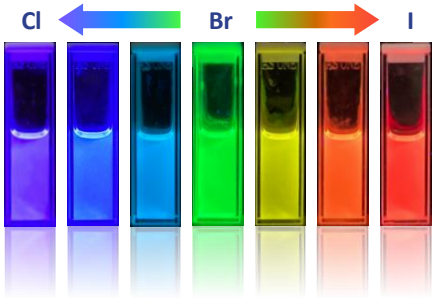


PeQD has the feature of being a narrow FWHM of the spectrum.

e.g.) In the case of green-emissive PeQD
- Narrow FWHM → obtained the pure Green.

Light-emitting materials with a narrow FWHM have high color purity, which **enables vivid and colorful depictions**.

- High color tunability in the vis. range



By controlling the halogen ratio and particle size, PeQD can control the emission color from purple to red. By combining these technologies and creating an optimal synthesis recipe, it is possible to easily tune all colors of visible light.

We have also established the method of **precisely controlling the emission wavelength in 1 nm**.

Technologies of preparing PeQD

Possible to Prepare PeQD with High Optical Properties
- With Low Energy, Low Cost, Mass Production -

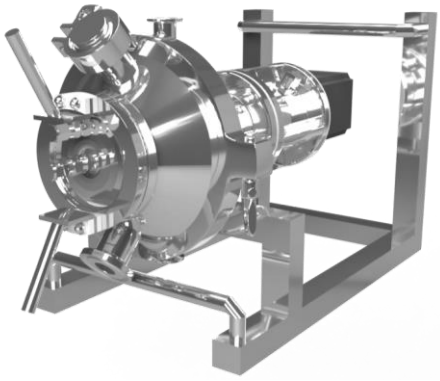
We have established mass production of PeQD based on Ligand Assisted Reprecipitation (LARP) method which is a small-scale preparation method as the basic technology. Here, we have developed a preparation method of PeQD by continuous flow synthesis system "Forced Thin Film micro-Reactor (FTFR)". FTFR is an ideal method for the mass synthesis of PeQD while maintaining optical properties that are the same values as preparing PeQD by the LARP method.

- Ligand-assisted reprecipitation (LARP)

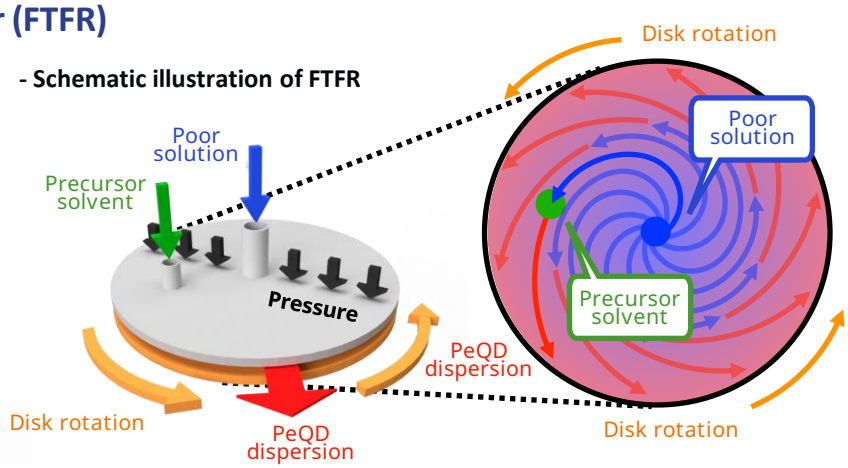
By mixing the precursor solution and poor solvent, resulting in obtaining PeQD.

LARP is a method to easily prepare PeQD by mixing a precursor solution (good solvent) with a poor solvent.
In the previous method (e.g. hot injection method), it is necessary to prepare PeQD under the high temperature and nitrogen atmosphere. On the other hand, it is possible to prepare PeQD **under the room temperature and ambient atmosphere in the LARP method**, which is superior to the conventional methods in terms of low energy and low cost. We have already succeeded in developing recipes for PeQD with high optical properties, high dispersibility, and high recovery rates.

- Force thin film micro-reactor (FTFR)



- Schematic illustration of FTFR



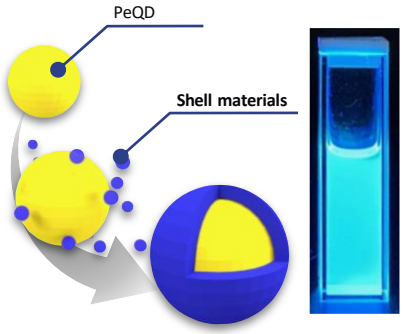
Our groups developed a scale-up preparation method of PeQD by FTFR, which is the continuous flow process. By mixing the precursor solution and poor solvent in the two disks, it is possible to mix two solvents uniformly, resulting in obtaining PeQD dispersion with high optical properties continuously. In addition, PeQD with almost the same properties can be synthesized based on LARP recipes.
We have successfully established the **continuous flow process (mass synthesis process) of PeQD over 5,000 mL/hr** from 10 mL scale.

Performance of PeQD

Development of Reliable PeQD

It is essential to increase the reliability of PeQD to achieve industrialization.
Our group at ISE CHEMICALS Corp. and Yamagata Univ. is researching the preparation and functionalization of PeQD. In addition, a group of three companies, including these two companies and ZEON Corp., is developing composite materials of PeQD and high-performance polymers.

- Surface treatment

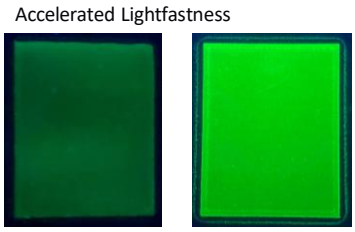


The surface treatment significantly improved the optical properties of PeQD.

The optical properties of PeQD are strongly influenced by its surface state.

We have already succeeded in producing red, green, and blue PeQD with high PLQY and stability by our proprietary surface treatment such as core-shell structure and unique ligands.

- Additives for dispersion

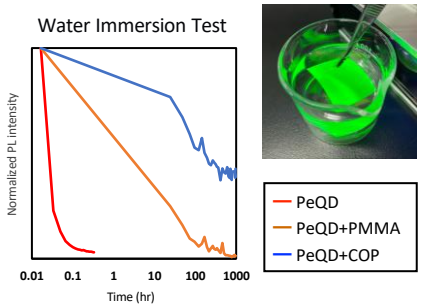


Our PeQD thin film showed high photostability against intense light exposure of 1000 W/m^2.

The optical properties of PeQD were found to be affected by the dispersion medium.

The dispersion medium for PeQD was adjusted by adding the optimal additives. As a result, the stability of PeQD was significantly improved.

- Composite materials



Significantly reduced PL degradation by the PeQD-polymer composited materials.

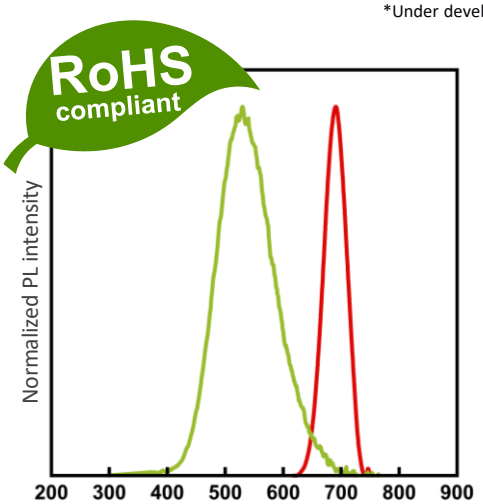
Water is a natural enemy of PeQD and is known to significantly degrade its optical properties.

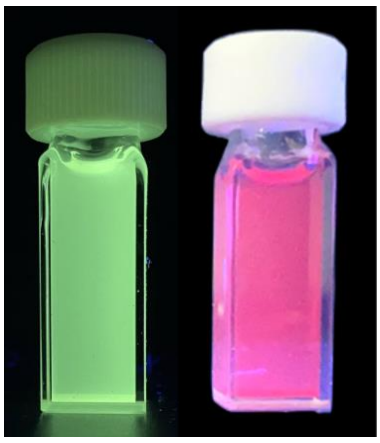
With our PeQD compositing technology, we have been able to improve water resistance tens of thousands of times.

Development of Pb-free PeQD

- Toward a Sustainable Society -

*Under development





PeQD contains the lead (Pb). It must be used below the concentration regulated by the RoHS Directive.

To solve the problems, our group has tried to reduce the amount of Pb to create a sustainable society while maintaining the abundant nature. We have reported one of the few successful cases of lead-free PeQD. We will continue research and development to further improve lead-free PeQD.

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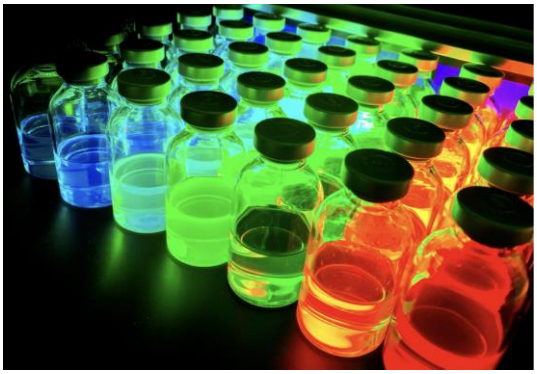
Sample Line-up

High optical properties of PeQD

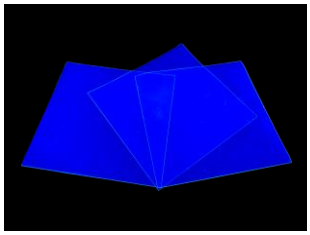


ZEON Corp. / ISE CHEMICALS Corp. / Yamagata Univ. have provided samples for R&D to promote the practical application and development of PeQD.

If you are interested in our PeQD in any way, please contact us!

- PeQD dispersion and film

- Blue



*Under development

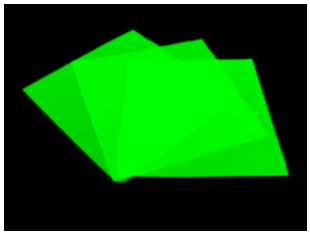
Optical properties

PLQY ≒ 100%
FWHM ≦ 20 nm

Emission wavelength

- **461 nm ($CsPbBr_3$)**
- **480 nm ($FAPbBr_3$)**

- Green



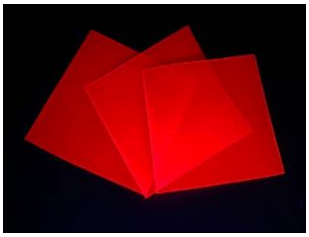
Optical properties

PLQY ≒ 100%
FWHM ≦ 25 nm

Emission wavelength

- **510 nm ($CsPbBr_3$)**
- **532 nm ($FAPbBr_3$)**
- 535 nm ($FAPbBr_3$)

- Red



*Under development

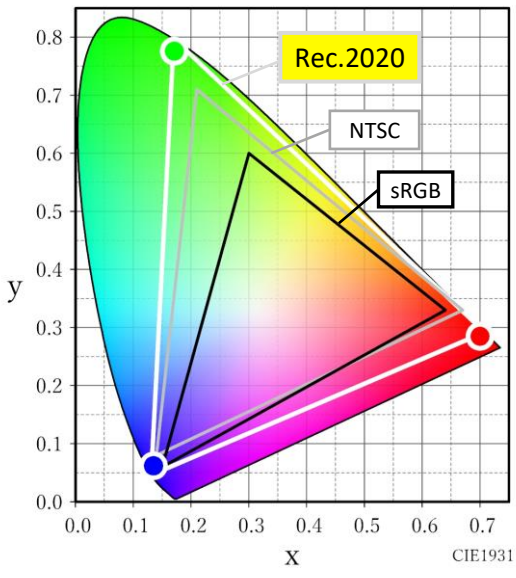
Optical properties

PLQY ≒ 100%
FWHM ≒ 40 nm

Emission wavelength

- **608 nm ($Cs_xMA_{1-x}PbI_3$)**
- **635 nm ($MAPbI_3$)**
- 780 nm ($FAPbI_3$)

Our PeQD



Our PeQD has reached **over 95% coverage of Rec. 2020**, the next-generation color gamut standard.

We aim to develop LEDs based on PeQD materials and implement them in displays.

If you have any other requests about emission wavelength, please contact us.

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PeQD empirical study

Versatile applications for PeQD

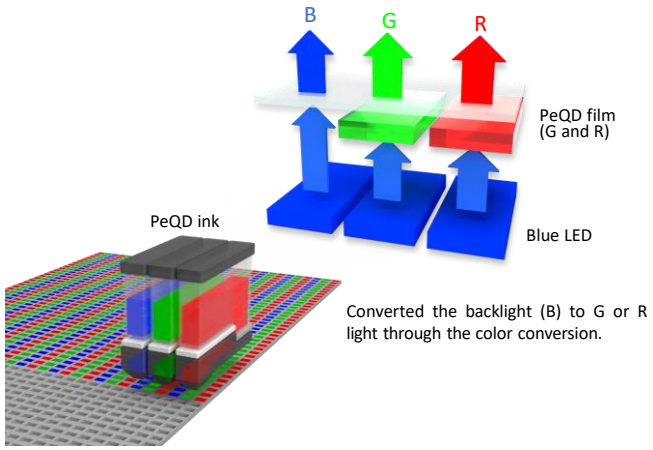
PeQD with excellent optical properties is expected to find applications in wavelength conversion films for displays, x-ray scintillators, biological imaging, photonic crystal transistors, films for agriculture and solar power generation, fixed LED lighting, and quantum dot lasers.

In particular, **we have focused on optical wavelength conversion films using PeQD.**

PeQD-incorporated films emit by absorbing the shorter wavelength compared to its emission wavelength (down-conversion). To utilize this principle of PeQD, it is possible to convert from UV and blue light to specific light through the color conversion film.

- Color conversion film for Display

*Under development



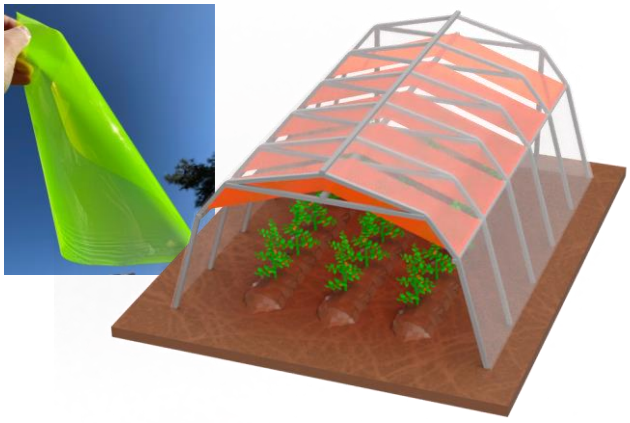
Converted the backlight (B) to G or R light through the color conversion.

PeQD films have been proposed as a means for realizing RGB light through the down-conversion of the blue LED. In the case of TV and smartphones, it will express the three primary colors of PeQD vividly by using the color conversion film. So, there is a need for early social implementation as a material that improves the color purity of LCDs and OLEDs.

We have successfully produced PeQD films. Shortly, our PeQD ink will be able to be applied to inkjet printing methods.

- Application for agriculture

*Under development



It is known that the growth of vegetables can be affected by irradiating them with a specific color of light. We believe that by using PeQD film, we can improve vegetable cultivation and create new value.

To create new value from PeQD and PeQD film, we are developing a wide range of applications.

Contacts

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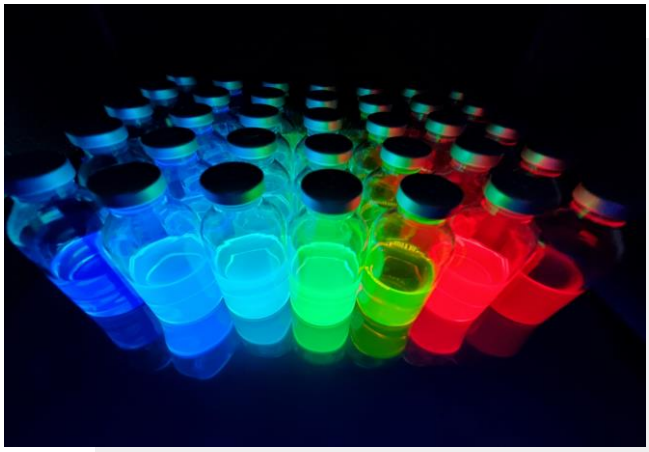
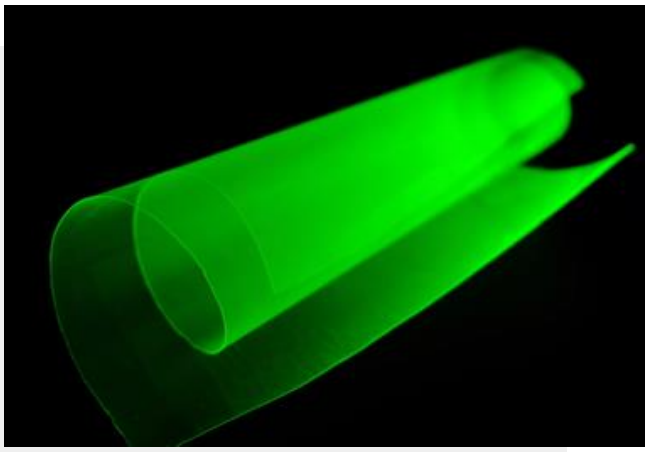
ISE CHEMICALS





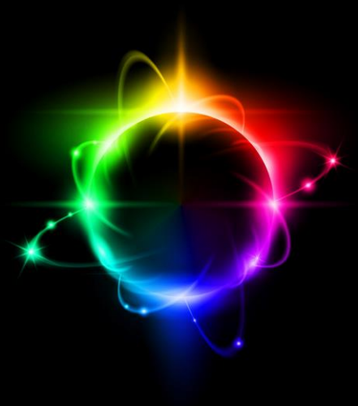
Iodine × Organic Electronics =

Specialty Plastics × Smart Device =

Raw materials, including iodine, are one of the world's leading elements in Japan.

Obtaining raw materials from the earth and developing technologies to create new materials and functions.

Organic electronics and device technology for achieving harmony between humans and information.



Creating a new world through the fusion of the above.