Supporting information for

Improved Long-term Reliability of A Silica-encapsulated Perovskite-Quantum-Dot Light Emitting Device with An Optically Pumped Remote Film Package

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A. Luminous efficiency vs. current
The samples with different BN doping concentrations were measured in an integrating sphere, and the luminous efficacy can be obtained. Although BN is not very absorbing in the UV range, the remnant absorption and extra scattering by BN particles themselves can induce certain level of UV photon losses. Thus in the real data, the efficiencies of samples with BN are always lower than those of samples without BN. In Figure S1, the in-chip devices with and without BN particles are plotted against driving currents. The highest efficiency of 60 lm/W can be achieved in the no-BN sample at low current level.

![Figure S1](image1)

Figure S1. The current-dependent luminous efficacy of in-chip devices.

B. The aged time evolution of in-chip devices

![Figure S2](image2)

Figure S2. The continuous aging data for in-chip devices with and without BN particles (a) normalized PLQY (b) change of peak wavelength (c) change of FWHM

One of the characteristics of these in-chip devices is the fast degradation after aging process starts. In less than one hour, the degradation in PLQY can be as large as 60% of the original values (as shown in Figure S2). The illumination capabilities were leveled out quickly as time proceeds. Similar deterioration can be observed in spectra characteristics as well. In Figures S2(b) and (c), both wavelength shift and Spectral width expansion changed dramatically and then slowly move towards shorter wavelength and wider side respectively.

C. The spectra of aged devices
The following graphs (Figures S3 and S4) are the fresh and aged spectra for various samples in this study. In both in-chip and remote film types of samples, the tail in shorter wavelength range should be noted which is not usual for most of the quantum dot degradation \(^1,2\). Due to the serious degradation in the in-chip devices,
the UV peaks were excluded in the spectra to make the suitable scope of the plots in Figure S4.

Figure S3 The comparison of spectra before and after the aging process (at 2714th hour) for remote film type of devices with BN doping of (a) 0 mg, (b) 0.5 mg, (c) 1 mg, (d) 2 mg.

Figure S4 The comparison of spectra before and after the aging process (at 2697th hour) for in-chip type of devices with BN doping of (a) 0 mg, (b) 2 mg.

The pictures of these devices at the end of aging tests are shown in Figure S5. For in-chip devices, nearly all green photons are invisible and the overall color is much more like a cyan or blue one. For remote film devices, on the other hand, the green color can still be seen, just like what is shown in the spectra in Figure S4.

|                     | BN-0mg | BN-2mg |
|---------------------|--------|--------|
| **In-chip devices** | ![Image](image1.png) | ![Image](image2.png) |
| ![Image](image3.png) | ![Image](image4.png) |
| **Remote Film devices** | ![Image](image5.png) | ![Image](image6.png) |

Figure S5. The hybrid PQD LED with current injection at the end of aging processes.

**D. TEM of fresh and aged perovskite quantum dots**

The transmission electron microscopic pictures of PQD@SiO₂ powders before and after burn-in (24 hours) can provide some important observation in this study. In Figure S6, the crossed bars show the estimated x- and y-direction of particle sizes. We use this as an estimate for the histogram plot in Figure 12.
E. The spectra of on-shelf degradation test.
In Figure S7, the spectra before and after a 247-day on-shelf storage are shown. Very little difference can be observed in both vacuum condition and air condition.

![Figure S7](image)

Figure S7 (a) The spectra of samples stored in the air. (b) The spectra of sample stored in vacuum.

F. The procedure to mix PDMS and quantum dots
The PDMS layer is formed by mixing the SYLGARD® 184 (silicone elastomer kit) which were bought from Sil-More Industrial Ltd, and in a ten to one ratio for polymer and the curing agent. Then the quantum dot powder and h-BN powder were measured by an electronic microbalance. All the substances (including PDMS, PQD@SiO$_2$, and h-BN powder) were then stirred and mixed thoroughly before filling into the lead frame. The filling composites were solidified in an environment of 70 °C. The combined weight of the mixture in every device is kept at 12mg total. So the ratio of QD composite vs. h-BN powder is 12:0, 11.5:0.5, 11:1, 10:2 for BN0, BN0.5, BN1, BN2 samples, respectively.

G. The calculation of estimated lifetime of devices
To properly evaluate the lifetime of the devices, a criterion called LT50, which means the lifetime to reach 50% of its initial value, can be linearly extrapolated from the last 2500 hours of data, as shown in Figure S8, and calculate the degradation of the 50% initial peak intensity. The math equation is as follows:

\[ \text{LT50} = \frac{(50 - \text{intercept})}{\text{slope}} \]

where the slope and intercept are linearly fitted parameters from the data we acquired in the continuous aging process for each device.
Figure S8. The illustration of LT50 calculation.

REFERENCE
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