The Effects of VOCs on LEDs

Outdoor lighting such as headlamps, floodlights, and streetlights using LEDs may employ sealed structures to achieve waterproofing and dustproofing. Within these sealed spaces, outgassing of volatile organic compounds (VOCs) from components surrounding the LED (e.g., organic compounds like adhesives and coatings) can cause a reduction in the LED's light intensity. This application note aims to deepen understanding of the effects of VOCs on LEDs and facilitate their effective utilization in the design of LED-based products.

Fig.1 Headlamps and Floodlights

1. What are VOCs?

VOC stands for Volatile Organic Compounds. It is a general term for organic compounds that easily volatilize at room temperature and pressure and exist as gases in the air. They primarily have molecular structures containing carbon and are widely present in our surroundings, such as the odor of paints and adhesives, gasoline vapors, and printing inks. VOCs have relatively low molecular weights and high volatility, making them prone to dispersing into the air. Furthermore, many VOCs possess properties as organic solvents, meaning they readily permeate polymeric materials like resins and plastics. This permeation can sometimes cause material degradation and performance deterioration in electronic and optical components.

In product design, it is essential to fully understand these properties and select materials and structural designs that suppress emission sources. Managing VOCs is a critical design element for achieving reliable products.

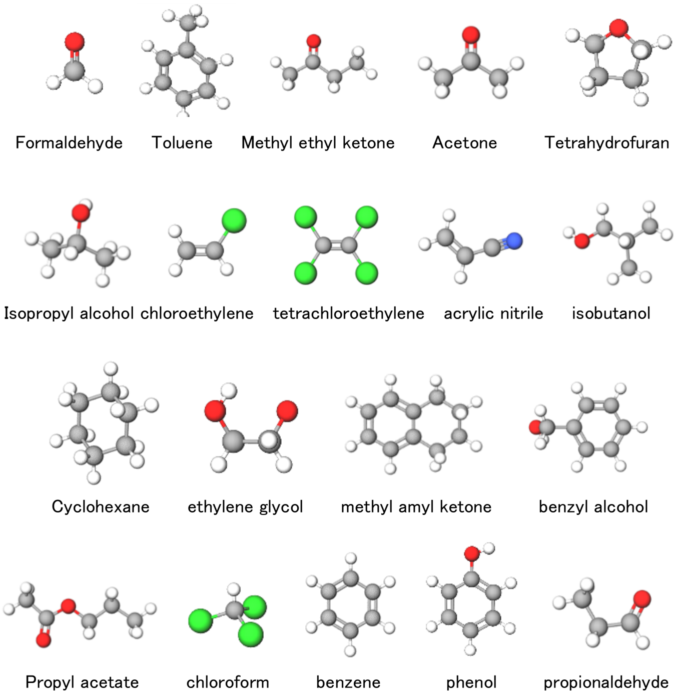


Fig.2 VOC Examples

※VOC substances excerpted from

"Ministry of the Environment's List of 100 Major VOCs"

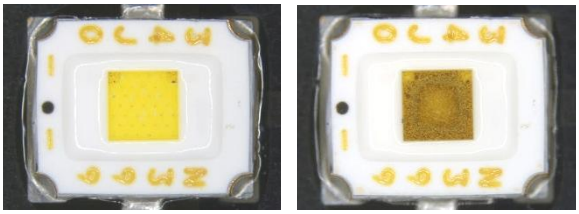
2. Effects of VOCs on LEDs

In LED products, phenomena such as reduced luminous flux, color shift, and discoloration of encapsulation resin or lenses can sometimes be caused by VOCs. These phenomena significantly impact not only visual quality but also product performance, lifespan, and reliability.

VOC molecules are highly volatile, making them prone to dispersing into the air and accumulating at high concentrations in enclosed spaces. Under such conditions, VOCs may adhere to the surfaces of LED lenses or encapsulation resins, penetrate into components, and undergo chemical reactions. This can generate pigments such as brown or yellow discoloration, which manifests as discoloration on lenses or light-emitting surfaces, directly affecting optical characteristics (Figure 3).

Specifically, light transmittance decreases, reducing luminous flux. Additionally, changes in the spectral distribution of light can cause chromaticity shifts.

These changes not only compromise the product's appearance quality but also shorten the LED's lifespan over the long term. Particularly when sealed structures are adopted in lighting fixtures or electronic devices, the problem tends to become more pronounced because VOCs trapped inside affect the LED components over extended periods. Therefore, correctly understanding the effects of VOCs and implementing countermeasures during the design stage is extremely important for ensuring product reliability.



No VOC impact　　VOC impact present

Fig.3 Example of VOC effects using HCNW115AJTE

3. Mechanism of Discoloration

Discoloration caused by VOCs is primarily induced by chemical reactions. As shown in Figure 4, VOCs that have permeated the encapsulation resin undergo oxidation and decomposition under the influence of light and heat, potentially generating brown substances through the rearrangement of chemical bonds.

These substances absorb and scatter light due to their visible light absorption properties. Consequently, the light transmittance of the LED decreases, adversely affecting luminous flux and color rendering. This discoloration phenomenon is fundamentally reversible in many cases. For example, changes in temperature and humidity, or the LED's own light emission, can decompose the brown substance, allowing it to return closer to its original state.

Silicone resin is sometimes used in the encapsulation resin for LEDs mentioned earlier. VOCs affecting LEDs, such as in headlamps, are generated by volatilization from component parts. These VOCs then cause problems by penetrating into the LED light source interior via the silicone resin.

A key point here is the difference in gas barrier properties among silicone resin types. Generally, phenyl silicone resins offer higher gas barrier properties than methyl silicone resins, effectively suppressing external VOC ingress. This can potentially reduce the risk of discoloration.

However, high gas barrier properties also mean that VOCs that have penetrated the resin are less likely to volatilize back out. Therefore, if VOCs do enter the resin, once discoloration occurs, recovery becomes difficult. These phenomena are more likely to occur as VOC concentrations increase.

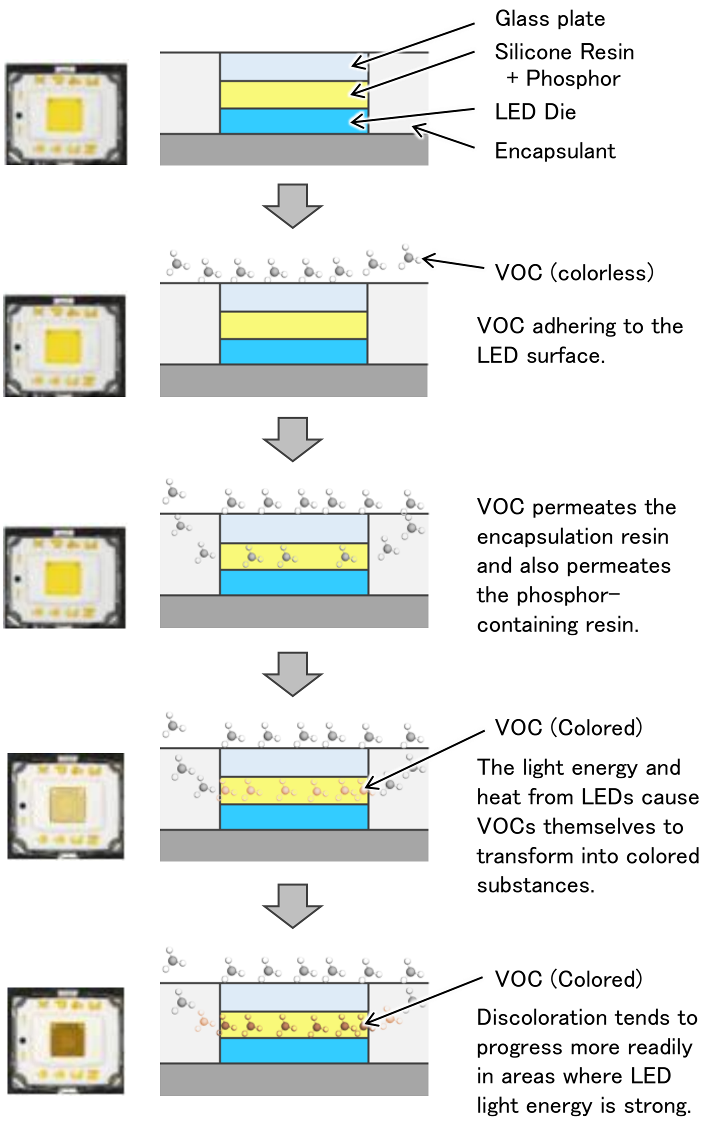


Fig.4 Discoloration mechanism caused by VOC

4. Risk Causes and Material Selection

Headlamps continue to evolve daily. Headlamp light sources have transitioned from incandescent bulbs to halogen lamps and then to LEDs (Figure 5).

Within this trend, adhesives, silicone rubber O-rings, resin-based coating agents, encapsulants, and other materials used in LED light sources, headlamp units employing LED light sources, and even lighting fixtures incorporating these components become sources of VOC emissions.

These materials may release VOCs during manufacturing or use, and they tend to linger and accumulate in enclosed spaces.

In LED products, the risk increases that emitted VOCs will adhere to or permeate optical components, causing discoloration or degradation of optical performance. Therefore, material selection during the product design stage is a critical point. Specifically, it is recommended to prioritize materials with low VOC emissions or low volatility.

When selecting materials, manufacturers may provide chemical compatibility lists or VOC evaluation data. Utilizing these resources to confirm whether target materials exhibit excellent chemical compatibility with LED components and possess long-term stability is vital. Furthermore, as outlined in subsequent chapters, conducting evaluation tests using discoloration and recovery tests with VOC sources, when necessary, enables more appropriate material selection.

Thus, to reduce VOC risks, material selection must prioritize chemical stability and environmental compatibility, not merely performance or cost. Achieving reliable LED products requires designers and materials engineers to collaborate on a design process that consciously incorporates VOC countermeasures.

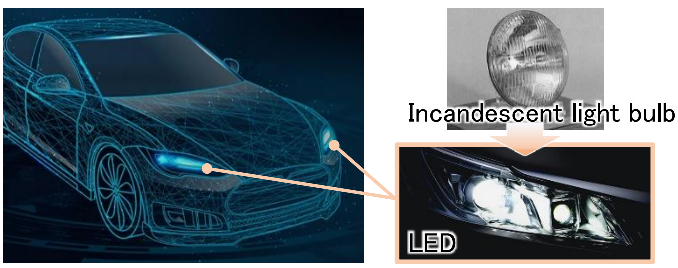


Fig.5 Evolution of Headlamps

Fig.6 LED light source (left)
LED Headlamp Unit (Right)

5. Design Countermeasure

To prevent the adverse effects of VOCs, various countermeasures are implemented during the design phase of LED products. For example, as a VOC countermeasure in LED luminaires, incorporating ventilation holes allows VOCs, which tend to accumulate inside the luminaire, to be efficiently expelled to the outside. This reduces the negative impact on LEDs caused by rising VOC concentrations. Incorporating airflow designs that utilize natural convection or thermal convection can promote VOC dispersion and help suppress localized accumulation. Additionally, ensuring ample internal space within the luminaire can dilute the concentration of generated VOCs, further reducing their impact.

These design insights and innovations contribute to maintaining stable performance in LED products and are crucial elements for preserving high quality even under harsh environmental conditions.

6. Test Methods and Evaluation Results

VOC discoloration evaluation cannot fully replicate real-world usage conditions. Due to the complex interplay of factors such as temperature, humidity, light conditions, and component placement, test environments inherently provide verification only under limited conditions. Therefore, the tests described below do not directly determine whether discoloration will occur in specific products. Instead, they serve as a reference evaluation to assess susceptibility to VOC effects.

〈Test Methods〉

This test aims to confirm the presence or absence of discoloration in LED components due to VOCs and the extent of its impact.

Test specimens containing VOC sources and those without were prepared for comparison. The evaluation, conducted in the following two-stage test, assessed the appearance discoloration over time and measured the output change and color shift in luminous flux.

1. Discoloration Test

The test specimen was sealed in a glass container with the LED and VOC source placed inside (Figure 7). Heating this specimen on a hot plate melted the VOCs, causing gas evolution. The LED was illuminated by applying its rated current, recreating an environment where both heat generation and LED light emission effects are present.

To further accelerate the test, evaluation was conducted while heating the test specimen (Figure 8). At this time, power was applied via a circuit board fixture to ensure safe illumination.

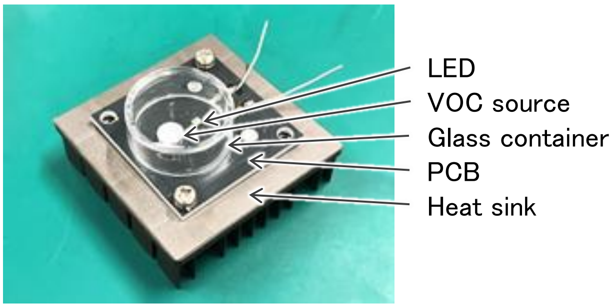


Fig.7 Test sample appearance

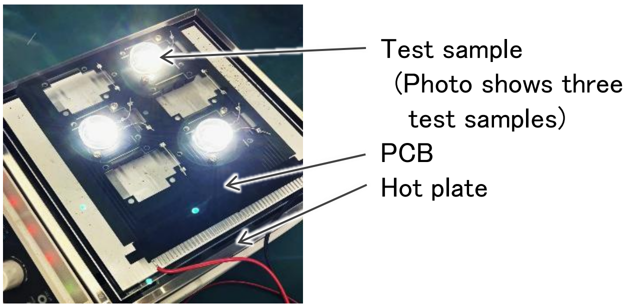


Fig.8 Discoloration Test Appearance

For evaluation, VOC sources were selected from chemicals known to emit VOCs. These substances were chosen for their melting points, which minimally affect LED fixture components, and for being solid at room temperature to ensure safe handling.

Specifically, 1-naphthol, biphenyl, and 2-hydroxy biphenyl were used as VOC sources in this test. This allowed accelerated evaluation testing by generating sufficient VOC gas inside the glass container, enabling efficient assessment of VOC effects on LEDs.

2. Recovery Test

After the discoloration test, the sealed glass containers were opened. The LEDs were then relit while fully exposed to the surrounding air to evaluate the recovery tendency of discoloration due to VOC volatilization (Figure 9). This allowed us to determine whether the discoloration was reversible and to assess the extent of recovery.

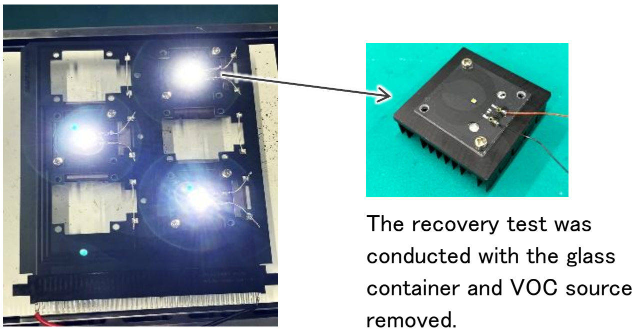


Fig.9 Recovery Test Appearance

〈Evaluation Results〉

Observation Results of VOC Discoloration and Recovery Behavior

In evaluation tests conducted in a sealed environment, no significant deterioration phenomena such as discoloration of the LED appearance or reduction in luminous flux were observed under conditions without VOC sources. However, under conditions where VOC sources were placed inside the glass container, clear discoloration of the appearance and a decrease in light output were observed (Figure 10, Graph 1).

Although the speed and degree of discoloration and recovery vary depending on the VOC gas concentration, under the test conditions, the relative luminous flux decreased to 5% or less after 5 hours of discoloration testing, and a recovery trend was observed after 10 hours of recovery testing.

Discoloration was particularly pronounced on the LED light-emitting surface. This is likely due to VOCs volatilizing and lingering within the enclosed space, penetrating into the LED package, undergoing chemical changes under the influence of light and heat, and subsequently generating pigment compounds.

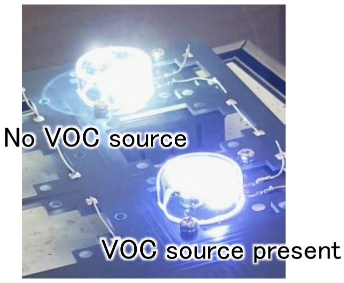
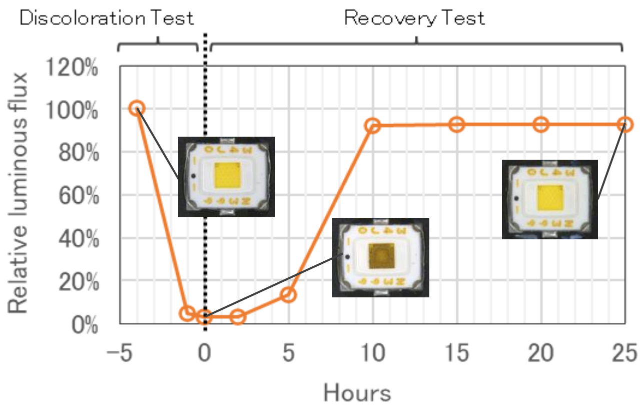
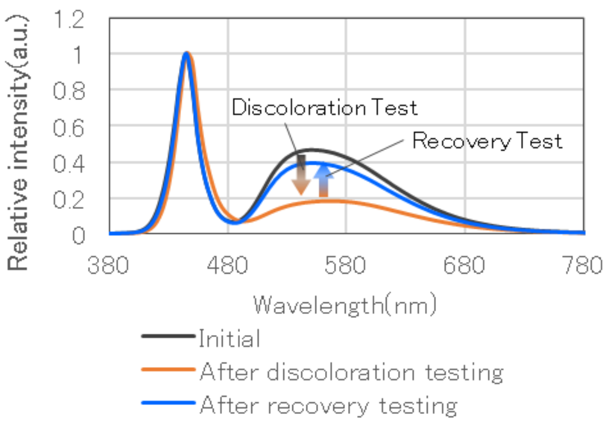


Fig.10 Differences in luminous appearance based on the presence or absence of VOC source

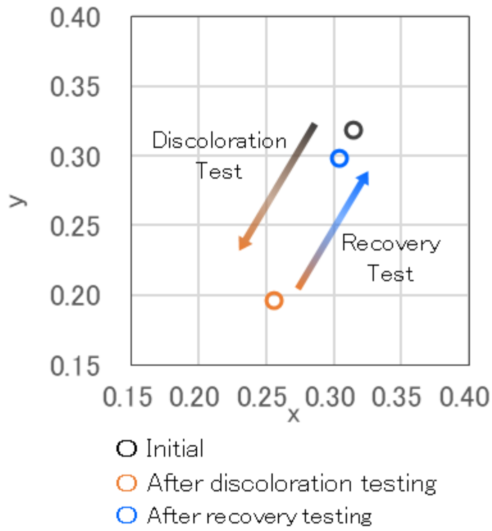


Graph 1. Luminous flux changes during VOC testing

※Recovery test start is designated as 0hr



Graph 2. Luminescence Spectrum Changes in VOC Testing



Graph 3. Color shift in VOC testing

When discoloration occurs due to VOCs, the emitted light becomes strongly blue. The shift toward blue emission is evident from both the emission spectrum and chromaticity changes (Graph 2, Graph 3).

This is thought to occur because heat and light increase the conjugated double bonds in VOCs, making electrons more mobile. Consequently, discoloration reactions proceed more readily even at lower energies. As a result, absorption of light on the longer wavelength side also increases, leading to the observed stronger blue appearance.

These findings suggest that the discoloration is primarily due to VOC-derived products, with minimal impact from degradation of the material itself. Furthermore, in tests aimed at confirming recovery behavior, discolored samples were exposed to ambient air after being released from a sealed state.

Continued illumination under these conditions showed a tendency for the degree of discoloration to decrease over time, with luminous flux also recovering. This recovery phenomenon is thought to result from the decomposition or removal of VOC-derived discoloration substances through reactions with atmospheric oxygen or natural volatilization.

Based on these results, the impact of VOCs on LED luminaires primarily stems from externally introduced VOCs undergoing degradation due to light and heat, leading to visible discoloration and performance decline. The findings indicate that this impact can potentially be mitigated through appropriate ventilation design and component selection.

7. Summary

VOCs are volatile organic compounds that readily evaporate from components surrounding LEDs and accumulate in enclosed spaces. When VOCs adhere to or permeate the surfaces of LED lenses or encapsulation resins, chemical reactions triggered by heat or light cause discoloration and degradation of optical properties. This leads to reduced LED performance and shortened lifespan.

Designers must understand VOC properties and utilize chemical compatibility lists and VOC evaluation data during material selection to verify compatibility with LED components and long-term stability.
Additionally, product design can mitigate VOC effects through measures like incorporating ventilation holes and ensuring adequate internal space.

Proper VOC management is one key to achieving high-performance, long-life LED products.