Introduction of High-reflective and Highly Thermal Conductive Insulating Inorganic Paints Suitable for Power Semiconductor Devices and LEDs

パワーデバイス、LED に適した高反射・高熱伝導な絶縁無機塗料の紹介

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キーワード；パワーデバイス、LED、無機塗料、メタルベース基板、絶縁性、高反射、高熱伝導、深紫外線、紫外線反射

Abstract

In recent years, while semiconductors have been sophisticated, the generated heat has increased. However, the use of resin materials having low heat resistance is not possible in the operating temperature area of next-generation power semiconductor devices and we have to use expensive ceramic materials. In LED industry, resin curing and sterilization markets using UV LED have been expanded, but the luminous efficiency decreases due to increase in generated heat. In order to solve these problems of next-generation power semiconductor devices and UV LED, we have commercialized functional inorganic paints that can solve these problems using a sol-gel method.

近年、半導体は高性能化する一方、発熱が増大している。特に SiC 系に代表される次世代パワーデバイスの動作温度域では耐熱性の低い樹脂材料の利用が不可能となり、高価なセラミックス材料を使用しなければならないという課題がある。また、近年、LED 市場では紫外 LED を利用する樹脂硬化や殺菌の市場が拡大しているが、発熱が大きいため、発光効率が低下するという問題がある。このような次世代パワーデバイスや紫外 LED の有する課題に対して、当社はゾルゲル法を利用して、これらに好適に利用できる機能性無機塗料を商品化したため、紹介する。

1. Introduction

In recent years, while semiconductors have been sophisticated, the generated heat has increased. In particular, the operating temperature of next-generation power semiconductor devices typified by SiC-based ones is higher than 250℃. Conventionally, the maximum operating temperature of Si-based power semiconductor devices was around 175℃. Therefore, inexpensive resin materials had been used as an insulating heat dissipating material.

However, the use of resin materials having low heat resistance is not possible at 250℃ or higher where next-generation power semiconductor devices are operated. Therefore, there is a problem that we have to use expensive ceramic materials as insulating heat dissipating materials for next-generation power semiconductor devices.

The LED market has grown rapidly due to the practical use of blue LED. Recently, UV LED with a short wavelength has been developed and resin curing and sterilization markets using LED have been expanded. However, UV LED has a larger calorific value as compared to blue LED and the luminous efficiency decreases. In order to maintain the luminous efficiency, the improvement of heat dissipation is important. Furthermore, conventional highly-reflective resins are deteriorated to yellow by the action of UV radiation. Such resins have a very low UV-reflecting ability and are not available for UV LED. Therefore, we needed to either extend the area of a LED substrate electrode as an alternative or give up UV reflection capacity.

In order to solve these problems of next-generation power semiconductor devices and UV LED, we have developed paint-like products utilizing a sol-gel method. Furthermore, we have commercialized a functional inorganic paint which is suitable for next-generation power devices and UV LED by imparting various functionalities.

2. NC-series functional inorganic paints

NC-series functional inorganic paints are paint products which use sol-gel method as a basic technology. There are three basic features as below:

(1) Inorganic cured film can be obtained by heating at 300℃ or lower after painting the substrate.

(2) Due to the strong chemical bonding with metals, a metallic/inorganic hybrid material is easily obtained. Therefore, no extra heat resistance is generated in the adhesive layer when used as an insulating heat dissipating material.

(3) Its cured product has extremely high insulation resistance and the insulation is secured even if it is thin. Therefore, it is possible to lower the thermal resistance.

We have developed three products having a further functionality in addition to above basic features (a high thermal conductive paint, NC-T5, a high-reflective paint, NC-RA, and a deep UV reflective paint NC-RC). NC-T5 and NC-RA have already been commercialized. We introduce more information about the three products as follows.

2-1. A high thermal conductive paint, NC-T5

NC-T5 is a high thermal conductive inorganic paint which can directly form insulating film on metals such as aluminum and copper without using any adhesive or the like.

The thermal conductivity of the insulating film is about 4.4 W/m・K. In addition, the insulating film has an extremely high breakdown voltage of 60 kV/mm or higher. Therefore, NC-T5 film can ensure a sufficient dielectric breakdown voltage even if it is thin. As a result, it is possible to improve the heat dissipation of the substrate.

Since the insulating film and the metal material are chemically bonded directly, it is not necessary to use any adhesive or the like. This also contributes to the heat dissipation improvement of the substrate.

The insulating film has high heat resistance available up to 350 ℃ and can also be used for next-generation power semiconductor devices. Therefore, it is expected that NC-T5 film is used for low-end next-generation power semiconductor devices as a replacement for conventional resin materials.

Fig. 1 shows an example that NC-T5 is painted and cured onto the aluminum heat sink.

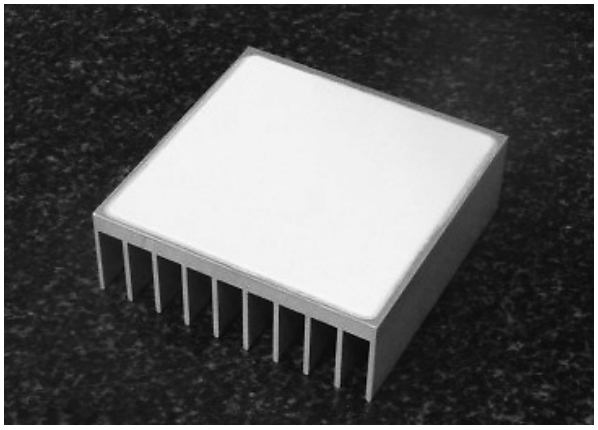


Fig. 1. Example that NC-T5 is painted and cured onto the aluminum heat sink.

2-2. A high-reflective paint, NC-RA

A high reflective inorganic paint, NC-RA, can form a high-reflective film without deterioration having excellent reflection characteristics at 360-400 nm, near UV region which is used for resin curing. Based on these characteristics, NC-RA can be suitably used as a high reflective material for the near UV LED used for resin curing.

Fig. 2 shows the spectral reflectance in the visible light region of NC-RA cured film. This indicates a high reflectivity of 90% or higher at 380-780nm, visible light region.

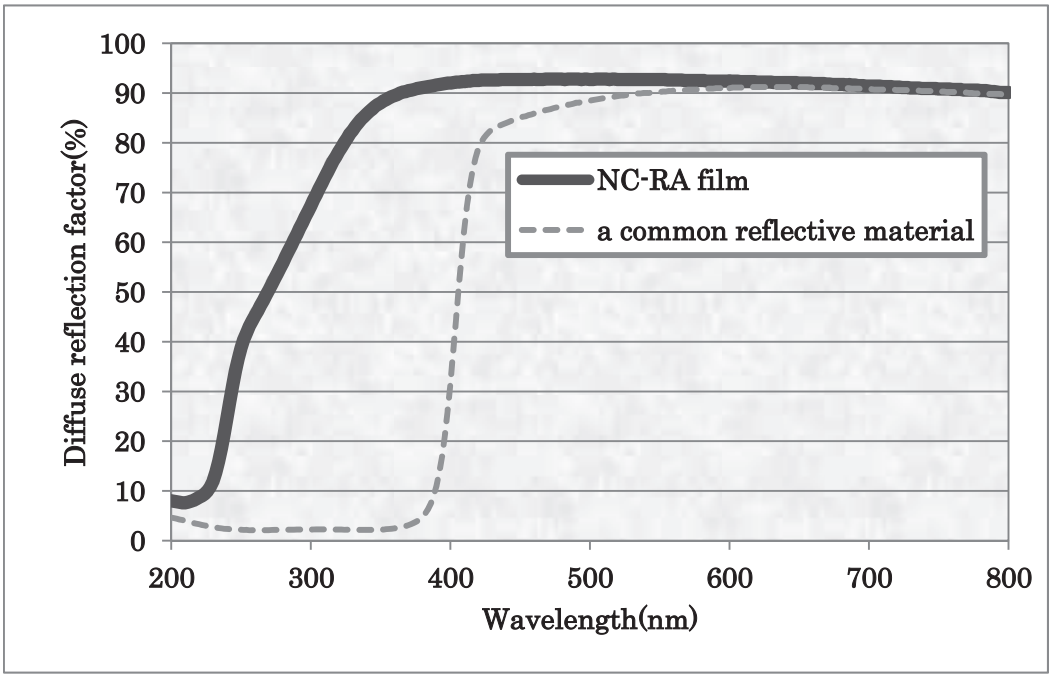
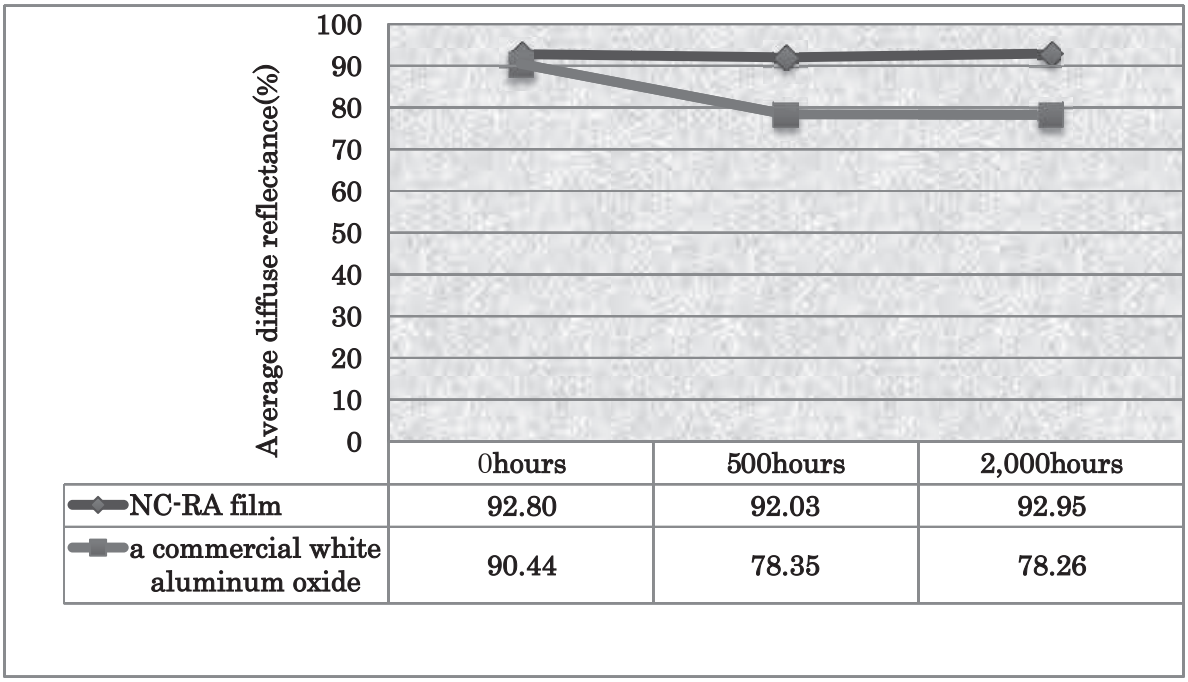


Fig. 2. Spectral reflectance characteristics of NC-RA film having a thickness of 50μm.

Since the film has extremely strong resistance against UV light, any deterioration such as yellowing does not occur even if deep UV which is more intense than near UV is irradiated.

Fig. 3 shows the average diffuse reflectance of wavelength, 360-740nm, before and after irradiation of 254 nm UV.

This indicates that the diffuse reflectance of NC-RA film does not decrease and holds 90% or higher even after irradiation for 2,000 hours whereas the diffuse reflectance of a commercial white aluminum oxide decreases at 500 hours.



	0hours	500hours	2,000hours
NC-RA film	92.80	92.03	92.95
a commercial white aluminum oxide	90.44	78.35	78.26

Fig. 3. The average diffuse reflectance of wavelength, 360-740nm, before and after irradiation of 254nm UV.

We introduce this highly-reflective inorganic paint, NC-RA, that can be applied to a metal base substrate taking advantage of such properties. In addition, as an application example, Fig. 4 introduces how to use it as a metal base substrate which has high insulation and high thermal conductive and is highly reflective. The substrate is composed of an electrode circuit/NC-RA layer/NC-T5 layer/Al plate.

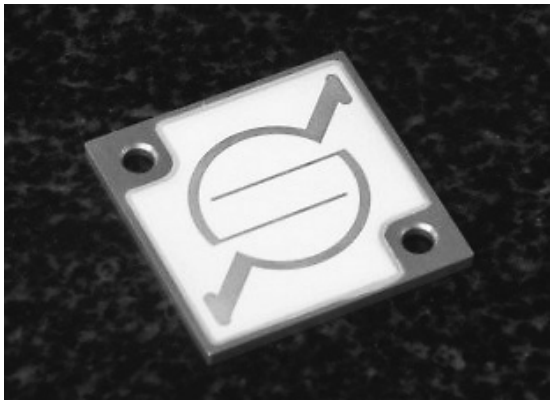


Fig. 4. An example of the metal base substrate
(electrode circuit/60 μm NC-RA layer/60 μm NC-T5 layer/2mmt aluminum).

2-3. A deep UV reflective inorganic paint, NC-RC (new product)

UV is used for resin hardening and deep UV with a shorter wavelength is used for a light source of air cleaners and water clarification system. A deep UV reflective inorganic paint, NC-RC, has a high reflectivity near the wavelength of 260nm which is highly effective in sterilization. In addition, NC-RC is little deteriorated by UV. With these characteristics, it is expected that NC-RC is used as a highly-reflective material for deep UV LED mounted on a sterilizer. It can also be used for forming a thin film on a metal substrate as same as NC-T5 and NC-RA.

Fig. 5 shows the spectral reflectance in the UV region of NC-RC film. NC-RC has a reflectivity of 80% or higher at 265nm.

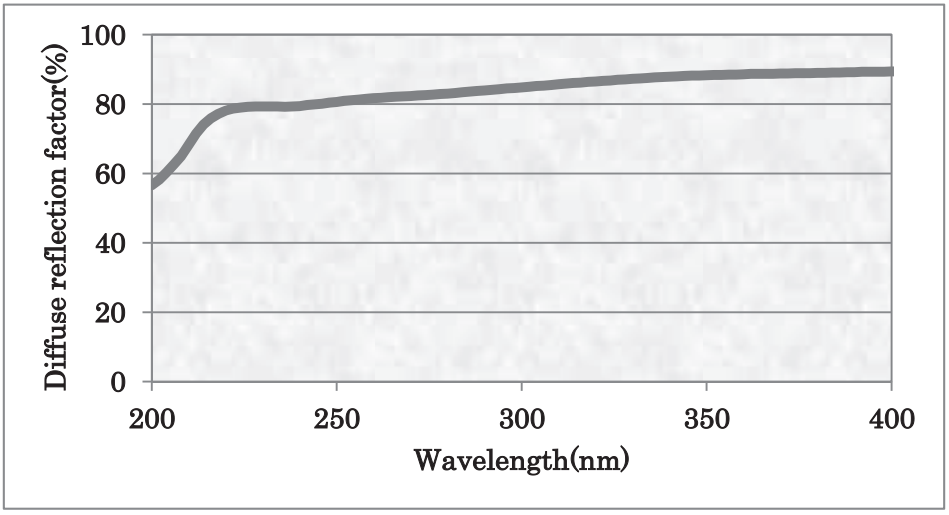


Fig. 5. Spectral reflectance characteristics of NC-RC film having a thickness of 50μm.

2-4. Typical specifications

Table1 describes typical specifications of functional inorganic paint cured films.

Table1. Basic characteristics of cured films (typical values).

Model number	NC-T5	NC-RA	NC-RC (Under development)
Type	High thermal conductive type	Highly reflective type	Deep UV reflective type
Thermal conductivity	4.4 W/(m·K)	1 ～ 2 W/(m·K)	Unknown
Breakdown voltage	60 kV/mm or higher	30 kV/mm or higher	60 kV/mm or higher
Reflectance	–	90% or higher (average: 360- 740nm)	80% or higher (at 260nm)
infrared emissivity at 100℃	0.81	0.90	0.88
relative permittivity	5.5	7.4	3.8
upper temperature limit	350℃		
adhesion properties	Adherable to aluminum, copper, nickel, alumina and aluminum nitride.		

3. Future market deployment

We are advancing the deployment of this functional inorganic paint aimed at the application to mainly next-generation power semiconductor devices and UV LED field as mentioned at the outset. The manufacturing system has already been prepared for 100kg/month of NC-T5 and NC-RA and we plan to further enhance the production capacity in the future.

In addition, as a further improved product with a high thermal conductivity, we are intensively developing a product with a thermal conductivity of 10 W/(m·K) or higher. Thereby, it is expected to improve a further cost performance for next-generation power semiconductor devices.

With respect to the high-reflection type, on the other hand, we have developed a deep UV reflective inorganic paint, NC-RC, that can be used for deep UV LED and already started supplying samples. The cured product of this paint has a high reflectance in the wavelength range of deep UV and is a revolutionary material that has no degradation such as yellowing due to deep UV. We expect this material to play an important role in the further efficiency improvement of deep UV LED.

Nippon Tungsten Co., Ltd. will continue commercialization activities for next-generation power semiconductor devices and UV LED field where the market growth can be expected and contribute to the market.