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Microarc oxidation coated magnesium alloy radiator for light emitting diode: Microstructure, thermal radiative and dissipating property

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ABSTRACT

Light emitting diode (LED) as a new generation light source whose lifetime and luminescence efficiency drop rapidly with the P-N junction temperature (T_j) increase. In this paper, a high emissivity ceramic coating fabricated by microarc oxidation (MAO) on magnesium alloy radiator enhanced the heat dissipation of LED. And the effects of MAO coatings with different phase composition on infrared emissivity and T_j were studied. The results show that Mg-Si-O and Ca-Mg-Si-O coatings exhibit a high emissivity up to 0.8 at 623 K within 8–20 μm wavelength range. The formation of $CaSiO_3$ phase in Ca-Mg-Si-O coating contributes to the short wavelength shift of the high emissivity region due to the enhanced lattice vibration absorption. The increasing coating surface roughness is beneficial to promote the emissivity. The enhanced thermal radiation with coated magnesium radiator significantly promoted the heat dissipating of LED. Compared with the uncoated magnesium radiator, the Mg-Si-O and Ca-Mg-Si-O coated samples with oxidation time of 10 min enable the temperature of LED to drop approximately at 6.2 °C and 7.3 °C, respectively.

1. Introduction

Light emitting diode (LED), with a variety of unique properties such as high efficiency, energy saving, environmental protection, long-lasting, fast response and so on, is dedicated to lighting applications and lighting equipment [1]. However, the lifetime shortens by half and luminescence efficiency drops by about 15% when the LED P-N junction temperature (T_j) increases by 10 °C [2] (T_j: Junction temperature is the highest operating temperature of the actual semiconductor in an electronic device, which refers to the actual temperature of P-N junction for LED, and the specific details will be discussed in the Section 2.4). Thus, to reduce the T_j is the essential problem to improve LED lifetime and luminescence efficiency. Traditionally, some methods were put forward to solve the heat dissipation of LED, such as different kinds of management of LED packages [3–5], the materials with high thermal conductivity of substrate and interface materials, and the heat sink adding a radiator to enhance heat dissipation. The substrate materials with high thermal conductivity such as aluminum nitride, alumina, copper and aluminum have been extensively used [1,2,6–14]. Recently, to develop the new types of light weight Mg alloys with high thermal conductivity as heat sink or radiator of LED have aroused the increasing interests [15–17]. The various methods mentioned above are limited to enhance heat transfer to enhance heat dissipation, while the heat dissipation by infrared thermal radiation with high emissivity surface is usually neglected.

In this work, microarc oxidation (MAO) method is developed to fabricate high emissivity ceramic coatings on magnesium alloy radiator for LED, and further verify the efficiency of enhancing heat dissipation. Magnesium, as one of the most capable eco-materials [18], have a variety of potential applications such as aerospace, automotive and electronics industries, which is attributed to their unique characteristics such as low density [19], high specific strength, good electromagnetic shielding [20], good dimensional stability good machinability [21] and high thermal conductivity. However, when serving in some circumstances such as heat exchangers, heat dissipation surface of electronic device carrying backplane in electronic industries (3C products, such as high power LED), the heat transfer characteristic by infrared thermal radiation of magnesium alloy or their protective coatings plays a crucial role on calculating the total heat transfer and transient temperature field. Since thermal radiation dominates heat transfer in a high temperature environment, a high emissivity coating is desirable to be deposited to reduce the heat flux to the metallic substrate by radiation [22]. Theoretically, the desired emissivity value is better as high as 1.0. While, to obtain the highest emissivity is extremely difficult, because emissivity values are determined by the lattice vibration absorption of specific materials, the crystal lattice is corresponding to a certain wavelength range [23]. So, to design the high emissivity coating materials on magnesium alloy surface remains the great challenge. The effective heat dissipation by coatings formed on radiator will promote the durability and reliability of LED.

MAO method has been commonly used to fabricate ceramic coating on magnesium alloys for improving the corrosion resistance property [24–34]. Recently, MAO also exhibited the potential application in

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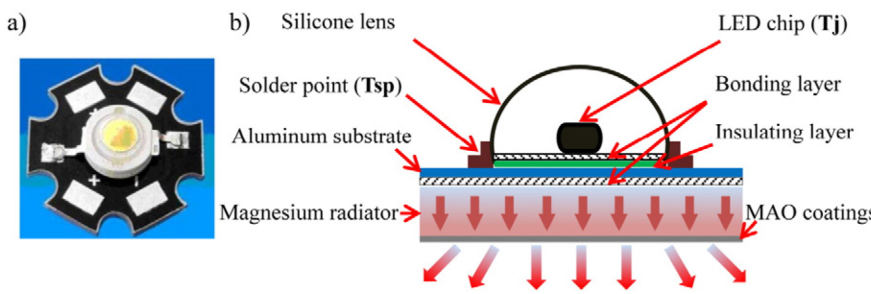

Fig. 1. LED and the structural diagram of LED package: a) LED, b) the structural diagram of LED package.

elevated temperatures circumstance due to their excellent high temperature stability [35–37]. The high emissivity coating formed by MAO on titanium alloy has the advantages of high infrared emittance in certain wavelength range, favorable heat dissipation and high bonding strength with the metal substrate [38]. While, the MAO coatings formed on magnesium alloy as radiating thermal management purpose in the elevated temperature conditions or in the heat dissipation of electronic products (e.g. light-emitting diode LED) were rarely mentioned.

The main objective of this paper is to investigate the effects of enhanced thermal radiation with coated magnesium radiator on thermal dissipating of LED. The thermal radiative emissivity of the MAO coated magnesium alloy radiator at elevated temperature in the medium infrared spectral range were comparatively investigated, so as to provide an alternative method for the preparation of high emissivity thermal management ceramic coatings. The influence of two coatings with different phases on infrared emissivity property was also studied. Thus, this work deals with the relationships between the specially modified coatings microstructure and the infrared emissivity of MAO coated magnesium alloy radiator for LED.

2. Experimental

2.1. Coating preparation

The commercial AZ91D alloys, with chemical nominal composition (wt.%) 8.73% Al, 0.70% Zn, 0.15% Mn and balance Mg, are employed in this study. Samples for infrared emissivity testing cut into a disc (30 mm diameter and 1 mm thick) were used as the substrate. The surface of the samples was grinded with 800# and 1000# abrasive paper, then ultrasonically cleaned in distilled water followed by acetone. The samples were used as anodes, while stainless steel plates were used as cathodes in the electrolytic bath.

A 65 kW microarc oxidation device provides the voltage waveform. The electrical parameters were fixed as follows: voltage 400 V, frequency 600 Hz, duty cycle 10.0%. The Mg-Si-O coating was prepared from the solution of Na_2SiO_3 (10.0 g/l) (Tianjin KAITONG Chemical Reagents Ltd.) and NaOH (10.0 g/l) (Tianjin TIANLI Chemical Reagents Ltd.) in distilled water, and the test sample Mg-Si-O5 and Mg-Si-O10 with two kinds of coating thickness (12, 20 μm) were fabricated using 5 and 10 min of oxidation time, respectively. The Ca-Mg-Si-O coating was prepared with 5 g/l $Ca(H_2PO_4)_2$ (Tianjin GUANGFU Fine Chemical Research Institute) addition into the based solution of Na_2SiO_3 (10.0 g/l) and NaOH (10.0 g/l), and the test sample Ca-Mg-Si-O5 and Ca-Mg-Si-O10 with two kinds of coating thickness (15 and 22 μm) were fabricated using 5 and 10 min of oxidation time, respectively.

2.2. Coating characterization

The coating thickness was measured with a coating thickness gauge (Minitest 600B, Germany EPK.). The surface roughness of the coatings was determined by profile and roughness tester (JB-4C, Shanghai optical instrument Co.). The surface morphologies of coatings were observed using scanning electron microscopy (SEM, S4800, Hitachi Co.). The surficial pore percentage and average pore size changes were obtained via Image Pro Plus 6.0 software (Media Cybernetics, Bethesda, MD, USA). The phase composition of the coatings was analyzed by X-ray diffraction (XRD, Philips X'Pert) using a CuK_α radiation.

2.3. Emissivity measurements

Infrared emissivity values of the samples were carried out on an infrared radiometer based on Fourier transform infrared spectrometer. The radiation emitted by the sample surface at 623 K is detected by a Fourier transform infrared (FT-IR) spectrometer (JASCO FT/IR-6100), and its radiance is compared with the radiance of a reference blackbody radiator. A blackbody is an idealized physical body that absorbs all incident electromagnetic radiation, regardless of frequency or angle of incidence, and at the same time it emits all the energy that it absorbs with the same absorbing spectrum. That is to say, emissivity value of the reference blackbody is equal to 1 [39]. In this way the infrared emissivity value of sample is obtained based on the principle of radiation comparison with sample radiance to blackbody radiance. The FTIR spectrometer used in this experiment can rapidly scan spectra at a high spectral resolution and broad wavelength range of 3–20 μm.

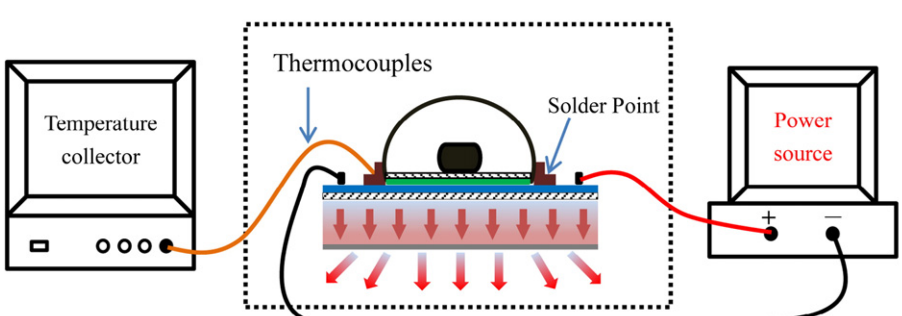

Fig. 2. The measuring equipment diagram to measure solid-point temperature of LED.