ELECTROCHEMICAL ALUMINA TECHNOLOGY FOR HIGH-BRIGHTNESS LED APPLICATIONS

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Abstract – High temperatures near light-emitting regions are common for high-brightness LED systems. The cooling problem for these devices can be solved only by effective heat sink from the light-emitting region to the cooler environment. We propose the most effective heat sink for the high-brightness LED systems fabricated on the anodized aluminum substrates. 30 – 50 µm thick nanostructured alumina layer formed by the electrochemical alumina technology offers good electrical isolation and excellent thermal transfer. Copper conductors are applied to the alumina layer and light-emitting diodes are mounted directly on the surface. This approach allows the most important heat resistance component, i.e. a dielectric substrate, to be excluded. As a result, the record low heat resistance is reached and the heat sink is more efficient. So, the electrochemical alumina technology allows the heat sink problems that were considered as an insurmountable obstacle to be solved.

I. INTRODUCTION

Recently light-emitting diodes (LED) progressively replace incandescent lamps. High brightness and long life are characteristic of modern LED illuminating equipment. Today leading companies produce commercially LED lights. They find an application for street lighting, signaling and transport illumination engineering. If take into consideration a spread of automated bonding technologies, high-brightness LEDs fabricated for the surface mounting (surface-mountable devices – SMD) are the most promising.

High temperatures near light-emitting regions are common for high-brightness LED systems. Heating from external source including direct sun rays is added to the heat dissipated by high-brightness LEDs themselves. As is well known, LED radiation intensity falls sharply as temperature increases and is halved when temperature increases to 70 – 90ºC relative to the room temperature. Saying by the language of solid-state physics, a role of nonradiative carrier recombination increases, and Saying by the language of engineering, a coefficient of efficiency decreases. In addition, high temperature results in the LED quick degradation. Until recent times this problem was not solved in full measure. Evident advantages of LED systems in comparison with incandescent lamps force producers to limit LED temperature requirements up to 85°C. However, real-life environment may be much more severe. For example, if LED is placed in the closed passenger compartment and affected with direct sun rays, temperature near the light-emitting region may be as high as 100 – 120°C.

II. RESULTS AND DISCUSSION

The LED cooling problem may be solved only by the effective heat sink from the light-emitting region to the cooler environment. The substrate utilized is a key component of the power and thermal management scheme. The current study focused on the electrochemical alumina technology (ELAT) for the substrate fabrication [1-2] to provide the most effective heat sink. The technology includes in succession the following basic operations: (i) aluminum surface finish, (ii) aluminum anodization, (iii) metal deposition, (iv) metal patterning, (v) LED mounting.

The 30 – 50 µm thick dielectric alumina layers are formed in the 10% aqueous solution of the oxalic acid by the high-speed porous anodization [2] at the constant current densities 100 – 150 mA/cm^2 at 20ºC. In this case the anodization rate is 5 – 10 µm/min to allow the alumina layer of the desired thickness to be grown for 5 – 10 min. Electrophysical parameters of the alumina films fabricated are: a breakdown voltage is more than 1 kV, a heat resistance of the 50 µm thick alumina layer is $6.25 \cdot 10^{-6}$ $m^2 \cdot K/W$.

One interesting characteristic of the ELAT technology is the capability of forming solderable conductors directly onto heat sinks thereby simplifying the assembly of power systems. A 1.5 µm thick nickel layer is deposited chemically on the dielectric alumina layer. Then the surface sensitizing is performed in the 5% solution of $SnCl_2$ in 5% HCl for 2 min at the room temperature with further surface activation in 1% solution of $PdCl_2$ in 5% HCl for 1 min at the room temperature. Next, the activated substrate is cleaned and subjected to the electroless nickel plating in the aqueous solution consisted of boric acid (15 g/l), lactic acid (17 g/l), caustic soda (19 g/l), sodium hypophosphate (20 g/l), nickel sulfate (25 g/l),and thiourea (0.1 g/l). The process temperature is 95ºC, the deposition time is 10 min. the deposited film is heat treated at 200ºC for 1 hour.

A 30 µm thick conducting copper layer is formed on the nickel surface by the electrochemical deposition in the electrolyte consisted of copper sulfate (210 g/l), sulfuric acid (75 g/l), ethyl alcohol (10 g/l), urotropin (0.2 g/l) at the current density 20 mA/cm^2 at 23ºC.

Then the Ni-Cu metal layers are patterned by the conventional photolithography to form needed interconnection pattern. The layers are etched layer-by-layer. Copper is etched in the $FeCl_3 \cdot 6H_2O$ solution, nickel is etched in the HNO_3:H_2O diluted solution.

At last, high-brightness LEDs are mounted directly on the substrate surface.

Fig. 1 shows a high-brightness LED system formed on the anodized aluminum heat sink. The 50 µm thick dielectric alumina layer is formed on the flat aluminum surface, 30 µm thick copper metallization is formed at the anodized surface, and 40 LEDs (1 W power, 32 V supply voltage, and 1.5 A maximum current) were mounted.

For the successful application of anodic alumina some problems should be solved. Among them are: (i) an assurance of the alumina thermal stability in the range from -60ºC to +300ºC taking into account that the linear expansion coefficient of aluminum is 4 times higher than that of alumina; (ii) removal of the pore influence on the breakdown voltage relative to the substrate, leakage currents and insulation resistance; (iii) an assurance of the time stability of these parameters.

Figure 1 – High-brightness LED system on the anodized aluminum heat sink

To improve the thermal stability, a cyclic anodization regime is proposed. The voltage or current in every next cycle is taken to be more or less by 10 – 20%. Such cycles should be more than two. In the last cycle the voltage is set to be maximum possible for the taken anodization conditions. Time of every cycle should be more than 3 min. A porous alumina reconfiguration takes place at such the anodization regime because it is well-known that number of pores per the surface unit and pore diameter is directly proportional to the anodization voltage. So, when the voltage of the next cycle increases or decreases relative to the previous cycle, the porous alumina reconfiguration happens and any transition spongy layer arises. Number of such layers is equal to number of cycles, resulting in the thermal stability improvement. The anodization process should be finished with the maximum possible anodization voltage because of stresses at the alumina/aluminum interface. A tension stress appears in the alumina film while a compression stress appears in the aluminum due to difference in the coefficients of thermal expansion. Aluminum becomes plastically deformed near the alumina/aluminum interface due to the dislocation movement from grain boundary into the aluminum grain. By the way, so the structure of porous alumina is independent of the aluminum grain size. The elastically deformed aluminum zone appears else after the plastically deformed aluminum zone. Width of these zones is directly proportional to the diameter of the alumina pores at the above interface. Wider zones are, higher the thermal stability of alumina is. Thus, the cyclic anodization regime allows providing the desired alumina thermal resistance in the above-mentioned temperature range.

There is no doubt that pores in the alumina layer should be effectively filled with dielectric either completely or partially to provide the time stability of alumina parameters. To close pores, we use the Al_2O_3 or SiO_2 vacuum deposition.

III. Conclusion

We offer the most effective heat sink for the high-brightness LED systems fabricated on the anodized aluminum substrates. ELAT substrates consist of a highly thermally conductive aluminum alloy substrate with the anodic aluminum oxide layer electrochemically grown on the aluminum core. This anodized layer shows good electrical isolation (breakdown voltage no less than 1 kV) and excellent thermal transfer.

Since no organic materials are used, there is no degradation of properties during operation at high temperatures. The completely inorganic construction results in substrate characteristics that maintain their properties even at high continuous operating temperatures.

One interesting characteristic of this technology is the capability of forming solderable conductors directly onto heat sinks, thereby simplifying the assembly of power systems. The 30 µm thick copper layer is deposited electrochemically onto the anodized substrate. Because conductors can be applied directly to heat sinks, a wide range of circuit configurations are possible.

Traditional methods of removing excess heat from components have centered on the use of heat sinks with thermal grease or polymer pads to thermally connect the device to the heat sink. With the ELAT substrates, the entire board becomes the heat sink with no extra hardware (clips, screws, etc) required. In addition, copper conductors allow direct wire bonding from dice to the conductors. So, the electrochemical alumina technology allows the heat sink problems that were considered as an insurmountable obstacle to be solved.

References

[1] V. A. Sokol, *Anodic alumina*. Minsk, Belarus: Bestprint, 2011, 431 p.

[2] V. A. Sokol, "Extremal high-speed technique for the thick porous alumina film formation," *Doklady of the BSUIR*., No. 8, pp.84-88, 2010.