1. Foreword

Today, the LED (Light Emitted Diode) industry mostly gives priority to producing high-brightness application products. In addition, to enhance the brightness of the LED, it is inevitable to need to raise the operating current (from the early phased 0.3A develop to about 1A presently) and supply higher electric power (from the early phased 1W develop up to present 5W). As the LED produces light by combining electrons and electric operations, whose spectrum does not contain the infrared part, heat cannot be dissipated by the radiation mode. The LED is a "cold" light source. The current luminous efficiency of LED only reaches 10% to 20%. That is, there is 80% to 90% of the energy converted into heat. Thus if high heat generated by the operating high-brightness LED does not dissipate, it will accelerate the aging of the crystal grains, cause damage to the connecting line and the LED grain failure. [1]

The above discussion shows that in the pursuit of high-brightness and high power of LED application products, we must consider LED grain and frame junction temperature and thermal dissipation issues. According to statistics, about 70% of the LED products lead to failure because of the overly high temperature of junction, affecting product application level. Therefore, the research and development of LED cooling technology is quite important.

Today's high-power LED and electronics related products R & D are developed toward direction of lightweight, small size, high efficiency, high power and speed. However, the traditional way of LED heat dissipation has not been sufficient to cope with it. How to enhance the thermal dissipation performance is the most important key technology in related technological development [2]. Good heat dissipation technology is the essential elements for stable running of LED and electronics related products the important factors affecting life and quality of electronic products. In order to let the high-power LED and electronics-related products have good heat dissipation effect, a large number of technological methods related to heat dissipation have been proposed. However, most are still in the technology development phase. Alternatively, because of the restrictions of expensiveness, bulkiness and other factors, there is still some distance from actual use in commercial products [3].

To explore the technological methods which have been proposed, it can be found that it is the most simple high-power LED cooling technology to replace the use of conductive silver paste to stick thermally conductive Cu slug fixing grain and lead frame heat dissipation aluminum sheet. This is done by directly bonding thermally conductive Cu slug with pure aluminum, the formation of highly efficient direct heat conduction cooling structure. Therefore the topic points at the crux of the LED heat dissipation difficulty, puts forward of copper and aluminum bonding technology in the ordinary temperature and pressure, method to effectively improve thermal conductivity performance between LED die bond Cu slug and joining aluminum cooling module. This will ultimately make the LED's operation and applications perfect.

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copper bonded reaction is carried out at a eutectic temperature. Aluminum - copper juncture interface will produce atomic inter-diffusion, which makes the interface produce a local melting. Therefore, under close contact conditions Al - Cu will be able to produce the effect of the engagement easily [5]. In addition, because the thermal conductivity of dielectric metal diffusion reactants generated by aluminum - copper juncture interface is equal to aluminum or copper, the bonding method can effectively reduce the thermal resistance of the interface between the aluminum and copper. However, time of this diffusion bonding must be controlled to avoid too thick intermetallic diffusion reactants affecting the bonding strength of aluminum - copper juncture interface. [6, 7]

Veerkamp [8] bonded aluminum - copper with copper electrode and the connection terminals for the aluminum bus system of high direct-current bus systems. Aluminum - copper bonding in the bus connecting terminal application is the very important key technology [9]. Because the bus system withstands large current densities, the terminal junction must have a very low resistive impedance, to prevent a lot of heat resistance resulting from work, which causes burning of the terminal junction. Therefore, the use of aluminum - copper eutectic bonding will effectively solve the problem of electronic components contact resistance. Unlike traditional high temperature of aluminum - copper eutectic bonding method, Nichting et al [10] attempt to bond copper - aluminum in the low-temperature solid state, the bonding characteristics of which are dependent on pressing pressure, pressing time and temperature control. Although copper - aluminum bonding can be effectively reached, the required pressure up to 1-10 GPa, the process is time consuming and it is difficult to control the parameters. It is not practical in terms of the electronics industry application.

High temperature or high pressure processing environment is prone to let LED crystal block of epitaxial forming produce a qualitative change and fail. To overcome defect that the traditional diffusion bonding high-temperature process and solid-state bonding process is time-consuming and is not easy for LED packaging cooling process applications, this project uses a buffer layer made of nano and electroforming technology. It selects pure aluminum as the base material and coats the surface of the aluminum substrate with a contact layer of metal layer in room temperature and then the LED die bond Cu slug is cast on it. Copper and aluminum substrate manufacturing process completed, the circuit layer may be laid on its upper surface. Then connect the LED to form into application components. All the processes are completed at normal temperature and pressure, so this finished products and manufacturing methods of project can be used in a wide range of LCD TVs dynamic backlight module, flashlight, road lighting ..... etc. Moreover, because of their low cost, hopefully wide range of applications can be done. Meanwhile it also can serve for reference of sophisticated package structure layout of LED.

2. Experimental methods and processes

Summary of experimental methods

![Flowchart of experimental methods](image)

The topic selected the aluminum for the substrate of heat dissipation. While copper’s endothermic property is good, Aluminum has the following characteristics: Good ductility, electrical conductivity, thermal conductivity, heat resistance and radiation resistance. Combine these two metals into a product, having good heat convection, which can be of great help to the heat dissipation of LED.

Based on production process shown in Fig. 1, as shown in Fig. 2, first we use fine sandpaper to clean up aluminum substrate surface which is to be plated. Then place the aluminum in degreasing agent to wash. Remove surface oil. Repeat this action approximately twice or several times. Then place aluminum in pickling tank for cleaning, and remove alumina from the surface. (step one)

Because copper and aluminum plating is not able to work out directly, we first form a nano juncture layer on aluminum surface to facilitate metal layer plating to form the connection layer with copper (step two). The aluminum has finished pickling. Then place in a chemical solution for treatment. By way of the reduction reaction, a nano buffer layer is formed on the surface of the aluminum substrate to make it possible to easily plate on plating juncture metal layer subsequently. The following is copper and nano resultant reaction equation (Formula 1). The time and reaction agent dosage of the nano-reduction reaction must be strictly controlled so that the quality of the nano-bonding layer resulting from reaction can meet the requirement of a metal layer easy to plate and join.

$$2Al + X(OH)_2 = X + 2Al(OH)$$

Formula 1 Chemical reaction equation of nano buffer layer generated by a reduction reaction

After the nano buffer layer on the aluminum surface is generated, it must go through cleaning procedures to be cleaned in order to avoid residual chemicals affecting subsequent electroforming effect of metal layer. Then again, aluminum with nano-buffer layer on its surface is placed on electroforming machine. Pulse current passes
Step one. Select aluminum substrate, and clean it.

Step two. Place aluminum substrate surface in chemicals to generate the nano buffer layer.

Step three. Nano buffer layer surface is plated with a bonding metal layer.

Step Four. On the surface of bonding metal layer electroform die bond Cu slug.

Step five. On top of the Cu slug fix LED crystal grains.

Fig. 2 Production process of fixation of LED on aluminum heat dissipation element surface

through the nano buffer layer to plate the connecting metal layer (step three). Plating time of connecting metal layer must also go through the testing. Thickness must be uniform, which can make copper electroforming layer uniformly and tightly bonded in time of connection of electroforming die bond Cu slug.

Finally place aluminum substrate with finished plated metal layer in electroforming machine. Die bond Cu slug is cast on the juncture metal layer (step four). Power / time shall be tested in order to achieve the best value. Finally, by the use of eutectic bonding fix LED grain on a Cu slug die to achieve the purpose of LED die bonding on solid Cu slug and direct bonding with aluminum cooling module. The finished structure is shown in Fig. 3.

Fig. 3 Cross-sectional view of direct bonding structure of copper and aluminum

3. Experimental results and discussion

In order to understand process parameters really needed to effectively bond the interface between copper and aluminum, with regard to nano buffer layer reaction time, plating time of metal juncture layers, Cu slug electroforming time and voltage and current required by electroplating and electroforming this study has engaged in test and test work and observed its surface morphology. This was done to obtain a better quality of the finished product. The test’s variation of parameters is shown in Table 1.

By variation of the operating parameters, the completed electroforming surface morphology are not the same, the appearance of the surface of copper as shown in Fig. 4, five and six below.

Influence of plating metal bonding layer

From perspective of the above copper exterior surface reached by variation operating parameters, the completion of the nano buffer layer and subsequent plating layer will affect fastness of final die bond layer. By Fig. 4 and Fig. 5 it can be found under the circumstance of sufficient buffer layer and plating layer thickness and at last, eutectic copper layer can be uniformly formed on surface of the heat dissipation block. However, if the thickness of the buffer layer is sufficient but plating layer thickness is insufficient, severe spelling phenomenon will occur on ultimate electroformed eutectic copper layer, as shown in Fig. 6. Therefore, plated metal bonding layer must be thick enough to be able to produce enough tight bonding for electroformed die bond copper layer, otherwise in the

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Table 1 operating parameters for copper and aluminum bonding process test (Plating (electroforming) range dimensions: 75 mm × 35 mm)

|       | Nano buffer layer reaction time | Plating time of metal bonding layers | Plating operating current A & voltage V | Cu slug electroforming time | Cu slug electroforming operating current A & voltage V |
|-------|---------------------------------|--------------------------------------|----------------------------------------|-----------------------------|------------------------------------------------------|
| 1st   | 3min                            | 5min                                 | Current: 0.5A Voltage: 2.86V           | 5min                        | Current: 0.1A Voltage: 3.89V                         |
| 2nd   | 3min                            | 5min                                 | Current: 0.5A Voltage: 2.85V           | 60min                       | Current: 0.1A Voltage: 3.88V                         |
| 3rd   | 5min                            | 10min                                | Current: 0.5A Voltage: 3.14V           | 60min                       | Current: 0.1A Voltage: 4.38V                         |
| 4th   | 5min                            | 5min                                 | Current: 0.5A Voltage: 2.83V           | 60min                       | Current: 0.1A Voltage: 4.38V                         |

Fig. 4 Change the operating parameters and the surface morphology of the first sample

Fig. 5 Change the operating parameters and the surface morphology of the third sample

Fig. 6 Change the operating parameters and the surface morphology of the fourth sample

long electroforming process because of inadequate fastness of surface bonding even electroformed coating cannot be completed.

Even though the area of die bond electroforming copper layer is not big, metal plating layer still must reach a certain thickness, otherwise for the same reason it is unable to complete the die bond electroforming copper layer forming work. In addition, to prove this, the study specially chooses a specific small surface area of the fourth sample to make extension experiment, observing the results to demonstrate.

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According to Table 2’s parameters for completing the extension experiment, with die bond electroforming area of 5mm x 5mm, after metal plating layer time maintains 5min, continue to electroform die bond copper layer. It is expected that again electroformed copper layer thickness can reach 1mm. However, after about 7.25 hr. we
Table 2. Operating parameters of bonding process the fourth extension experiment

| Nano buffer layer reaction time t | Plating time t of metal bonding layers | Plating operating current A & voltage V | Cu slug electroforming time t | Cu slug electroforming operating current A & voltage V |
|----------------------------------|---------------------------------------|----------------------------------------|-------------------------------|-----------------------------------------------|
| 5min                             | 5min                                  | Current: 0.5A Voltage: 2.83V           | 60min                         | Current: 0.1A Voltage: 4.38V                  |

found it is still not able to cast up to 1mm thickness of the die bond copper layer effectively. This result proves the inferences of the experiment before. The plating metal contact layer must reach a certain thickness, otherwise forming work of die bond copper layer will not complete.

Correlative influence between electroforming time and the thickness

According to Faraday's Law of Electrolysis, via Faraday's Law of Electrolysis the experiment may obtain required value. Default of electroforming time 10 hr, desired electroforming thickness is 1mm. The amount of current required can be obtained therefrom.

**Faraday’s laws of electrolysis:**

\[
M = \frac{A \times I \times t}{F \times Z \times E}
\]

**NOMENCLATURE**

- \(M\): weight of separating out (cathode) or dissolution (anode)
- \(A\): atomic weight size
- \(F\): Faraday constant \((9.6485 \times 10^4\) Coul / mole\)
- \(E\): cathode efficiency
- \(Z\): number of charges
- \(t\): energizing time

Weight = (amperage × energizing time × Nickel valence number) / Ni atomic valence number × Faraday constant

Weight = area × thickness × density

Hence bring values into the foregoing expression required amount of working current in fixed operating time can be obtained:

\[
A = \frac{1.44 \times 0.1 \times 8.92 \times 2 \times 96485}{3600 \times 63.546} = 0.1A
\]

In addition, because the finished products from electroforming need to undergo after treatment, the factual thickness must be greater than 1mm. It is possible to extend the effective time of electroforming, so that the thickness increases.

According to the data of the preceding experiment, we can measure the thickness of the metal bonding layer and the copper layer respectively, to know the amount of electroforming time produce the effect of the metal layer. (Table 3)

Influence of microstructure between the juncture layers

In order to understand the actual interface situation between copper and aluminum in this experiment design, and actual reason how to reach bonding between metals with high proportion difference, the topic especially uses the scanning electron microscope to observe the surface morphology of each completed structural layer.

As shown in Fig. 8 and Nine, the Nano buffer layer has been able to provide a bonding between the aluminum layer surface and the plating layer, simply because the structure of the nano buffer layer is formed by way of linear staggered distribution to grow on aluminum structures. The linear structure voids happen to provide space for plated layer’s metal to be plated and grow. Therefore, the nano buffer layer and the plating layer will interlace and link to form a stable plating layer structure.

Under the premise of completion of adequate buffer layer and plating layer thickness processing, carry out final eutectic copper layer electroforming. At last, eutectic copper layer will be able to take shape uniformly on cooling block surface and no flaking will occur.

As shown in Fig. 10, by stable nucleation mode the copper will be able to present homogeneous spherical crystal structure, to achieve the purpose of this topic for studying pure aluminum’s direct bonding thermal conductivity copper slug.

Pure aluminum direct bonding thermally conductive copper slug heat sink performance tests

The results of the topic are to use low temperature normal pressure process to form copper and aluminum buffer nano bonding layer between Cu and aluminum heat dissipation substrate. We do not
Table 3 relationship between electroforming working parameters and the thickness of the die bond copper slug

|            | Metal contact layer thickness (T) | Electroforming die bond copper slug time (t) | Electroforming die bond copper slug operating current A & operating voltage V | Electroforming die bond copper slug thickness (T) |
|------------|----------------------------------|---------------------------------------------|---------------------------------------------------------------------------|-----------------------------------------------|
| 1st time   | 13μm                             | 5min                                       | A: 0.1A V: 6V                                                             | 18~20 μm                                      |
| 2nd time   | 12μm                             | 60min                                      | A: 0.1A V: 7.42V                                                          | 16μm                                         |
| 3rd time   | 12μm                             | 60min                                      | A: 0.1A V: 7.3V                                                            | 16μm                                         |

Note:
1. A current, V voltage, t time, T thickness.
2. Thickness measured in the form are the measurable maximum values.

use silver paste material with poor heat conductivity properties to stick die bond Cu slug and aluminum heat dissipation substrate. With copper and aluminum buffer nano bonding layer as auxiliary, by direct use of molten solder manner directly weld copper slug on the aluminum heat dissipation substrate surface, to enhance thermal conductivity of copper and aluminum bonding interfaces largely. Therefore, when the LED grain is energized to work, heat generated will be able to be directly transmitted to aluminum substrate to dissipate in a better heat conduction mode, thus enabling high-power LED light emitting element to extend life, to operate with higher working current, while achieving a stable and reliable illumination quality.

As shown in Fig. 11, by a single 1W white light LED with the original drive power 4V/700mA engage in different types of heat transfer interface. Observe its thermal dissipation performance. Compared to using traditional silver paste material to adhere die bond copper slug and aluminum heat dissipation substrate, by the use of the research results solder die bond copper slug directly to the aluminum heat sink substrate. From IR image measurement it is discovered that temperature of LED’s center decreases from 89.8 °C to 60 °C. The temperature difference reaches 29.8 °C. The thermal dissipation performance will increase nearly thirty percent or so.

With regard to 100 pieces 1W white LED collection package projected lighting applications, when we install a large number of LED of projected lighting, temperature in closed cabinet interior will rapidly rises. It is necessary to use bulky high-performance cooling components to force cooling. While the results of this study the low-temperature copper-aluminum straightly jointed technology can directly bond a high-power white light-emitting diode module to the surface of the aluminum radiator, provides highly efficient cooling mechanism. 1W white LED of raw driving energy 4V/700mA changes to access 3V/2A drive. Tested by undergoing 72 hours of lighting, it proves that it can effectively enhance the thermal dissipation efficiency of over 30%, the temperature differences shown in Fig. 12. The high power LED at work can enhance the relative power of more than 25%. In the long run high power output work does not produce any color shift, and the volume of auxiliary heat dissipation module can effectively reduce. It does reduce the cost of manufacture and installation, to achieve basic requirements of profitable products.
bond copper slug can be easily cast on the joining metal layer, which effectively enhances the LED thermal dissipation efficiency 30%. Its application can relatively enhance the power 25%. High power output working for a long time does not produce any color shift phenomenon. In addition, auxiliary heat dissipation module volume can be effectively reduced. It indeed reduces manufacturing and installation costs, to achieve the basic requirements of the profitable product.

4. Conclusion

Due to the large differences in the proportion of copper and aluminum, bonding capacity is very poor, and it is not easy to bond directly. If the interface is combined by improper handling fashion, great interface thermal resistance will be produced. Therefore, the use of traditional ways to deal with copper / aluminum-bonded interface will be unable to cope with the solutions for LED heat dissipation problems.

In this study, via the reduction reaction put aluminum into chemicals to generate a nanometer buffer layer and plate with bonding metal layer on the nanometer buffer layer to act as the interface for plating the copper metal layer. As a result, at last a die

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