Die Bonding of Single Emitter Semiconductor Laser with Nano-Scale Silver Paste

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Abstract

One of the most important steps in the manufacturing of laser diodes is bonding the chip onto some sort of sub-mount that allows the laser to be handled, durable electrical connections to be made, and heat to be conducted away from the laser itself. The ability to conduct heat away from the laser is critical in keeping operating temperatures low, thus improving the laser’s performance and its lifetime. In this study, it’s the first time to use nano-scale silver paste as a die-attach material for die bonding the laser diodes. Numerous tests have been carried out to check the silver paste packaged laser's performance, including electrical properties, spectral properties, far-field characteristics, thermal rollover characteristics and so on. The test results show that as a new interconnecting material, nano-silver paste has the potential to eliminate the deficiencies of the existing solders.

Keywords: nano-silver paste；semiconductor laser；die bonding

Introduction

High power semiconductor lasers have found increasing applications in many fields, such as pumping of solid state laser systems, medical systems, material processing such as welding, cutting, and surface treatment. [1] The performance and reliability of a semiconductor laser is greatly affected by the thermal properties of the laser assembly. However, the laser die-attach material can significantly impact the thermal performance and reliability of a laser assembly. [2] Therefore, the die-attach materials, which can provide interconnection, physical protection and mechanical support for the device, play an important role in the laser assembly.

Established technologies use either indium or gold-tin solder to mount the laser diode die to the heat-sink. Using them creates specific adverse effects. The indium solder, e.g., is easily oxidized, shows electro-migration at the high current level and tends to form solder voids. The gold-tin solder, in turn, is hard solder, which will produce stress caused by a mismatch in the coefficients of thermal expansion of the chip and mounting substrate. Because the material of the mounting substrate is copper, so when using the gold-tin solder, some kind of material should be employed in order to modify the coefficient of thermal expansion. This, however, will also affect the heat dissipation of the device. [2, 3] Consequently, the die-attach material of semiconductor lasers still needs to be improved. In this regard, it is crucial to find a better material for die bonding of the device. The new bonding material should have the property as high electrical conductivity and proper coefficient of thermal expansion to make up for the defect of the conventional die-attach material and so on.

Nano-scale silver paste is investigated. It has a number of advantageous characteristics that render its use favorable for die bonding the laser diodes. Compared to the existing solder, the pure silver joint shows feature of high melting point, high electric conductivity and high thermal conductivity which are good for heat dissipation. Even more importantly, the nano-scale silver paste possesses a uniform micro-porous structure that makes its elastic modulus equivalent to that of indium solder and much lower than that of gold-tin solder. Accordingly, it only introduces low thermal stress. What’s more, the nano-scale silver paste belongs to green electrical die-attach material. All of these characteristics are beneficial to die bonding the laser diodes.

In this study, the nano-scale silver paste will be used for die bonding the single emitter laser diode. The C-Mount diode laser was taken for example. C-Mount diode laser is one type of a packaged single emitter. Its structure is shown in Fig.1.

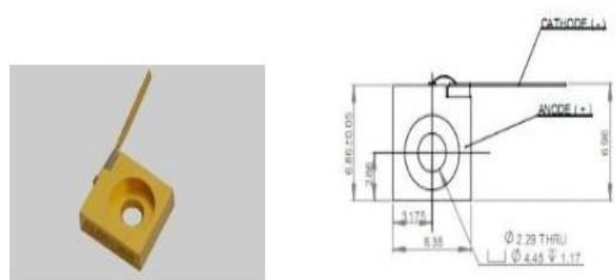

Fig.1. Structure of C-Mount semiconductor laser

The device’s electrical properties, spectral properties, far-field characteristics, thermal rollover characteristics were tested. The property of product with the new packaging material was initially explored.

Sample Fabrication

The sample preparation process is shown in Fig.2. Silver paste for die-attach containing spherical nano-scaled particles sized smaller than 50nm was obtained from NBE Tech, LLC. The paste was stencil printed to the C-Mount diode laser’s heat sink and low temperature sintered as the profile shown in Fig.3.to die bonding the chip to the heat sink. [4-6] GaAs based edge emitter structure 5W at 808nm chip with Au back coating ($0.8 \times 2 \times 0.13\ mm^3$ in size) and C-mount laser diodes' copper heat sink (plated with Au/Ni) were used. Paste thickness was approximately 30μm and 15μm before and after sintering respectively. Finished product is shown in Fig.4.

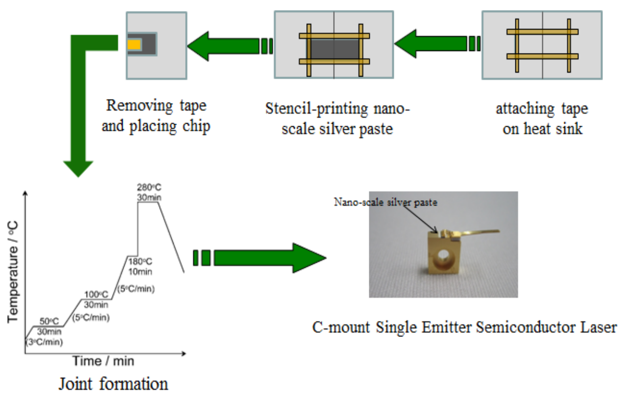

Fig.2. Preparation process of C-Mount laser diode

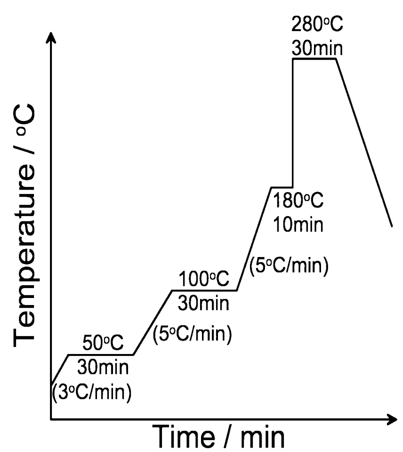

Fig.3. Low temperature sintering processing for nano-scale silver paste

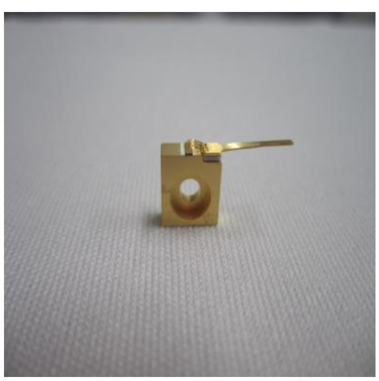

Fig.4. C-Mount semiconductor laser packaged with nano-scale silver paste

Experiments

First of all, in order to determine adhesive strength of low-temperature sintered nano-scale silver paste connected chip at room temperature, die shear test was conducted on 5 samples by using die shear test machine.

Secondly, to confirm the new product's operational performance, the product's electrical properties and spectral properties should be tested. Electrical properties like operating current, threshold current, slope efficiency and efficiency at operating current were measured, completed by spectral properties as peak wavelength, centroid wavelength, full width at half maximum, full width 90% energy. All tests will use high power semiconductor laser test system self-developed by the Xi'an Focuslight Technologies Co., LTD.

Thirdly, thermal resistance is a significant parameter to measure the new product's package reliability. In this study, wavelength shift method will be used to get the 5 samples' thermal resistance. [7] In addition, the thermal rollover curve also will be drawn to reflect the device's ability of heat dissipation.

Finally, far field characteristics test was conducted on 5 samples. Using the Xi'an Focuslight Technologies Co., LTD self-developed test system to record the data. According to the far field divergence angle to check the new die-attach material's package property and reliability.

Results and Discussion

1. Die shear test

Average shear strength, 16.7MPa, was gained from 5 samples at room temperature shown in Fig.5.

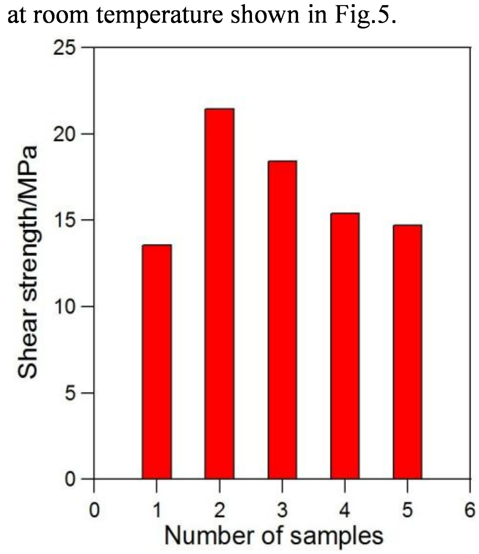

Fig.5. Shear strength distribution of nano-scale silver paste sintered C-Mount semiconductor laser

Because the shear strength of a chip is limited, so the die shear test data is hard to confirm the adhesive strength of the sintered nano-scale silver paste. However, all the samples failure is caused by chip inter plane separation shown in Fig.6. Consequently, the die shear test can ensure that the adhesive strength of sintered nano-scale silver paste is enough to package the C-Mount semiconductor laser. What's more, the nano-scale silver paste can avoid voids efficiently.

Fig.6. Failure section of chip inter plane separation

2. Functional test

The functional test consists of two parts, including the electrical properties test and the spectral properties test.

Ⅰ. Electrical property test

Through depicting the PVI curve to check the product's electrical properties' performance. The test result is shown in Fig.7.

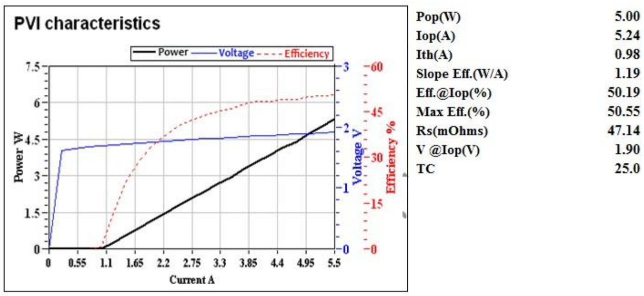

Fig.7. PVI curve of nano-scale silver paste packaged C-Mount semiconductor laser

The PVI curve is one of the important parameters to measure the device's packaging result. From the Fig.7, the device while working at room temperature, all the test data show good effect of the device. Even some of the parameters of this device are better than the device packaged with conventional solder, such as the efficiency at operating current, the slope efficiency and so on. Therefore, the electrical properties test indicate that the nano-scale silver paste as a new die-attach material to package the C-Mount semiconductor is highly feasible and potential for good development prospect.

Ⅱ. Spectral property test

Spectral sweep result is shown in Fig.8.

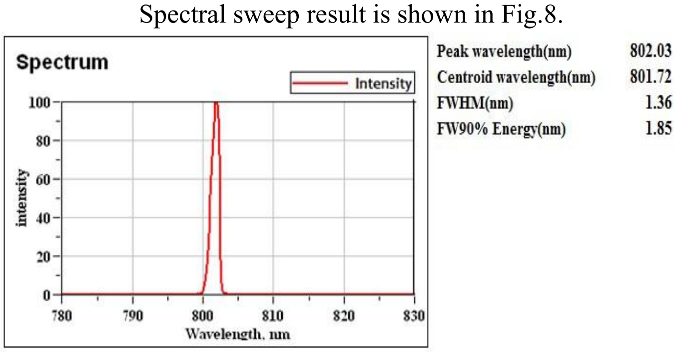

Fig.8. Spectral sweep result of nano-scale silver paste packaged C-Mount semiconductor laser

Semiconductor laser's spectral characteristics include two aspects, wavelength and spectrum width.

Wavelength mainly reflects the device's thermal characteristic. When the junction temperature of the device rises, the wavelength will shift toward longer wavelength. According to the test result, the device has relatively short wavelength. It means that, if the chip itself has no problem, the device has highly heat dissipation efficiency and low thermal stress. It makes the wavelength of the device is low.

Spectrum width mainly responds to the pump efficiency. It has two parameters, full width at half maximum and full-width 90 % energy included.

Normally, the narrower spectrum width is, the higher the conversion efficiency has. What's more, the high pump efficiency can reduce the device's heat burden and improve the device's reliability. Hence, controlling the spectrum width has important significance to the device's performance and reliability. Compared the test results, the device has favorable spectrum width.

Consequently, the function test confirms that the C-mount semiconductor laser die bonding with nano-scale silver paste is in good condition.

1. Thermal resistance calculation

Generally, when current is driven through laser diodes, its temperature generally increases consequently. If the bond between the chip and the carrier is good, the temperature raising will be smaller because heat is conducted away from the chip; if the bond is poor, the temperature rise will be larger because the heat builds up in the chip. One way to evaluate bond quality is to measure parameters of the laser that depend on its temperature. [7]Consequently, measuring thermal resistance of laser diodes is one way of testing bond quality of the device. The 5 sample's thermal resistance is shown in Fig.9.

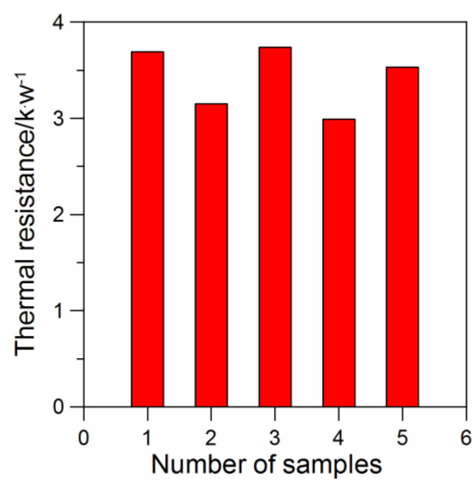

Fig.9. Thermal resistance of different samples

Average thermal resistance is 3.42K/W. To the C-mount semiconductor laser, the thermal impedance is low. Because the package technology is not mature enough, so the thermal resistance is not stable. Even so, the advantages of the silver joint still can be reflected, one sample's thermal resistance is 2.99K/W, if we use the gold-tin or indium solder, it would be hard to reach this result.

In order to check the device's bond quality and the heat dissipation potential, there is another destructive test to conduct on the device. Normally, the device's output power increases with the current increases. However, when the output power reaches a certain level, the output power's increasing phenomenon will disappear. This is because of the thermal rollover or irreversible catastrophic optical mirror damage (COMD). [8] For thermal rollover, when the current is driven through a device, its temperature increases. If the bond quality is not good enough, the generated heat cannot dissipate promptly and the heat will built up in the chip, which leads to power reduction although the device is not damaged. Hence, the thermal rollover test is imperative to check the device's bond quality. The C-Mount semiconductor laser packaged with nano-scale silver paste's thermal rollover test result is shown in Fig.10.

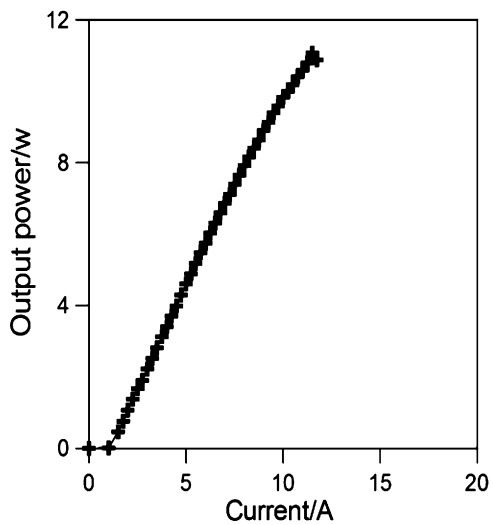

Fig.10. Thermal rollover of the device

When the current is 11.75A the device's output power starts to decrease and the thermal rollover phenomenon is emergence.

2. Far field characteristic test

As the dimensions of laser diodes active region are small, their output beam is highly divergent because of diffraction. The knowledge of the far-filed emission characteristics is essential for designing of optical systems which transform a laser diode output into a beam of the desired shape. [9]What's more, testing the far field divergence angle can also check the device's package performance and reliability. The camera is placed closely as possible to the laser diode so that it grabs the whole cone of laser diode radiation. Between laser diode and camera sensor (190mm) a set of absorption filters is inserted. They allow for an adjustment for intensity of incident light at the camera. A laser diode is driven with 4.5A current to avoid excessive heating of filters which may lead to distortions in the acquired image. The test result is shown in Fig.11.

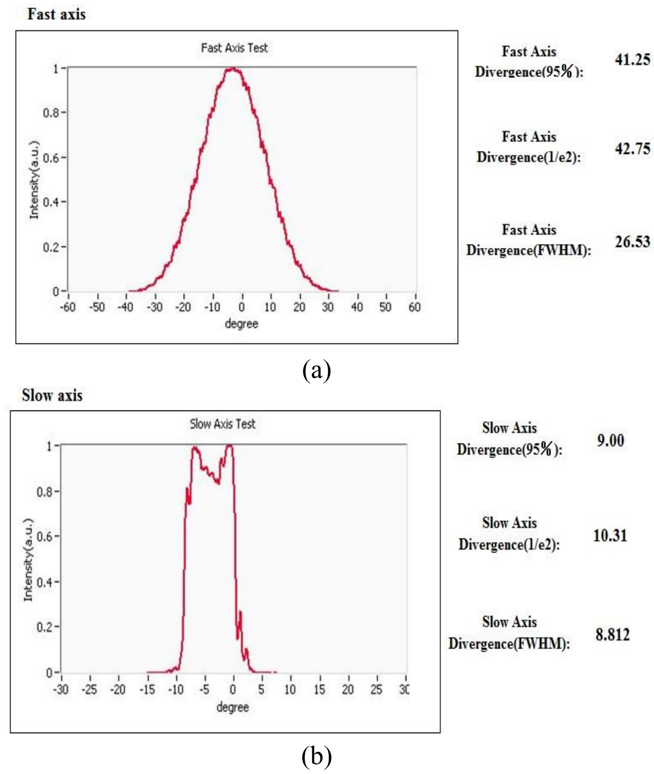

Fig.11. (a) Fast axis far field pattern
(b) Slow axis far field pattern

The result shows that the fast axis far field pattern is single mode and the light beam is high quality, however the divergence angle is large, but this phenomenon is normal. The C-Mount semiconductor laser packaged with traditional solder still has large divergence angle when test the fast axis far field characteristic, so some of the fast axis far field characteristics have the correlation to the chip itself. While the low axis far field pattern of the device is multimode and asymmetric. The beam shape is clearly disturbed and valleys are observed. The main reason is that the built up junction temperature in the laser greatly enhances the lateral index confinement which leads to existence of many multi-modes in the lateral direction [10]. Therefore, this phenomenon will also exist in the traditional solder packaged product. This test result is normal. However, at least, divergence angle of the low axis far field is small when the device packaged with nano-scale silver paste.

Conclusions

It is the first time to use nano-silver paste to package the C-Mount semiconductor laser. The die shear test, function test, far field characteristic test were conducted on the device. The thermal resistance of the device was also calculated in this paper. All of the performance tests show that the new interconnecting material is possibly applied to the field of semiconductor laser. In addition, the new die-attach material can avoid producing voids and have low thermal resistance and high conversion efficiency. These properties, in a certain extent, show the new product may have high reliability.

Nevertheless, these performance tests are not sufficient to ensure the reliability of the new product. Many reliability tests need to do to check the product with silver joint.

Acknowledgments

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