Novel Butterfly Type Laser Module Packaging Employing Nd:YAG Laser and Separated Clip of Stainless Steel

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The butterfly type laser module packaged employing separated clip of stainless steel and Nd:YAG laser is demonstrated in this study. The postweld shift (PWS) of fiber tip in laser module packaging is reduced by tuning the distance between separated clips. Using high-magnification camera with image capturing system (HMCICS) can accurately measure the direction and magnitude of shift on fiber tip. The benefit of using the HMCICS technique to determine the fiber alignment shift are quantitatively measure and compensate the PWS direction and magnitude during the laser-welded laser module packaging. This study makes it possible to probe the nonlinear behavior of the PWS by using a novel HMCICS technique that results in a real time quantitative compensation of the PWS in butterfly-type laser module packages. When compared to the currently available qualitatively estimated techniques to correct the PWS, the PWS is mostly reduced and lead to the PWS compensation is negligible in the laser module packaging process. The result shows that the coupling efficiency of laser module packaged by the separated clips, with 5 mm spacing and pre-compensation between 19.5 μm to 21 μm in Y-direction, can be improved to relatively higher coupling efficiency. The experiment result also shows that the coupling efficiency can be improved to 78%-99% after laser welding packaging employing separated clips. In comparison to the previous clip on laser module packaging, separated clip can effectively minimize the PWS to avoid PWS compensation. Therefore, the reliable butterfly-type laser modules with high yield and high performance used in lightwave transmission systems may thus be developed and fabricated.

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1. Introduction

One of the greatest challenges in the packaging of the laser modules using laser welding is to use a reliable and accurate joining process. In general, the connected components of the laser module package usually have different material properties such as different coefficients of thermal expansion (CTE), thermal conductivities, Young's modulus, Poisson's ratios, and yield strengths. During an Nd:YAG laser welding, and due to the material property differences between the welded components, the rapid solidification of the welded regions and the associated material shrinkage often introduced a post-weld-shift (PWS) between the welded components. For a typical single-mode fiber application, if the PWS induced fiber alignment shift by the laser welding joining process is even a few micrometers, up to 50 % or greater loss in the coupled power may occur[5-6]. The fiber alignment shift of the PWS effect in the laser welding process has a significant impact on the laser module packaging yield. Therefore, a detailed understanding of the effects of PWS on the fiber alignment shifts in laser-welded laser module packages and then the compensation of the fiber alignment shifts due to PWS effects are the key research topics in laser welding techniques for optoelectronic packaging applications[1-2].

There are many types of laser module package designs. The coaxial and boxed-type are the most common. The TO (transistor outline)-Can laser packages based on coaxial-type design are often selected when the fabrication cost is important and the performance requirement in lightwave transmission systems is not so high. The butterfly laser packages of the boxed-type designs, by contrast, are often used in higher performance devices that require a higher power output, a higher speed, a higher reliability, a thermo-electric cooler, and multiple components. In the process of packaging a butterfly laser package, a dual-beam laser welding system was used to connect the pigtail fiber assembly to the laser diode; whereas a three-beam laser welding system was used to connect the fiber ferrule to the TO-Can laser diode in a TO-Can laser package[6]. In a three-beam laser welding system, three laser beams were delivered symmetrically around the device[6]. However, in a two-beam laser welding system to weld a laser module with the geometrical arrangement of butterfly-type packages, it proved difficult delivering two laser beams symmetrically around the device. The effect of PWS on the fiber alignment shifts in butterfly laser package is much more sensitive than in TO-Can laser packages. Therefore, the PWS compensation is necessary in a two-beam laser welding system to weld the butterfly-type laser modules[1-2].

The process of solidification shrinkage induced PWS is a nonlinear behavior and it is a difficult task to analyze it. Previously, the power losses in butterfly-type laser module packages due to PWS could be qualitatively corrected by applying the laser hammering technique to the direction of the detected shift. Therefore, by applying an elastic deformation to the welded components and by observing the corresponding power variations, the direction and magnitude of the PWS may be predicted. Despite numerous studies on improving the fabrication yields of laser module packaging using the PWS correction in laser welding techniques by a qualitative estimate, limited information is available for the quantitative understanding of the PWS induced fiber alignment shift which can be useful in designing and fabricating high-performance butterfly-type laser module packages[1-2].

In this work, we present a quantitative probing of the PWS induced fiber alignment shift in laser-welded butterfly-type laser module package by employing a novel technique of a high-magnification camera with image capturing system (HMCICS). The benefits of using the HMCICS technique to determine the fiber alignment shift are to quantitatively measure and compensate for the PWS direction and magnitude during the welding process of the laser-welded laser module packages. This study makes it possible to probe the nonlinear behavior of the PWS by using a novel HMCICS technique that results in a real time quantitative compensation of the PWS in butterfly-type laser module packages, when compared to the currently available qualitatively estimated techniques to correct the PWS. Thus, the reliable butterfly-type laser modules with a high yield and a high performance used in lightwave transmission systems may be developed and fabricated[1-2].

2. Butterfly package construction and experiment

2.1 Laser Package Construction

A typical high-performance butterfly-type laser module consisted of a 1.5 or 1.3 μm laser diode, a single-mode fiber, a thermoelectric cooler (TEC), and an Invar housing, as shown in Fig. 1. The metallic plate, saddle-shaped clip, and fiber ferrule of the Invar housing materials with the very low coefficient of thermal expansion (CTE) of 1.5 x 10^{-6}/^{o}C were chosen to minimize thermal stresses and strains. In a butterfly package construction, the fiber ferrule and the submount-to-metallic plate assemblies were soldered joints, while the fiber ferrule-clip (FFC) and the clip-metallic plate (CMP) assemblies were welded joints. This fiber ferrule provided the fiber with a metallic housing necessary for rigidity and for the welding purposes, while the saddle-shaped clip provided the welding interface between the fiber ferrule and the metallic plate. In the process of fabricating a fiber ferrule, and in order to reduce the fiber alignment shift of the fiber-solder ferrule joints, an optimum approach for soldering the fiber ferrule was to solder the fiber near the center of the ferrule to reduce the initial fiber eccentric offsets and to select the AuSn hard solder for better material properties.

There were a total of ten welded spots on the laser-welded FFC and CMP joints, as shown in Fig. 1. In general, the laser welding of the CMP was implemented initially, followed by the laser welding of the FFC. The laser welding of the CMP was applied sequentially at the center, front, and rear. After the laser welding of CMP, the clip was fixed to the plate. The laser welding of the FFC may be done by using a different welding sequence. In this work, the front welding spots were formed first, followed by the laser welding of the rear welding spots, as shown in Fig. 1. The advantage of such a laser welding sequence was that it offered less welding induced alignment distortion during solidification shrinkage, and hence resulted in the stable welding of the FFC and CMP joints[1-2].

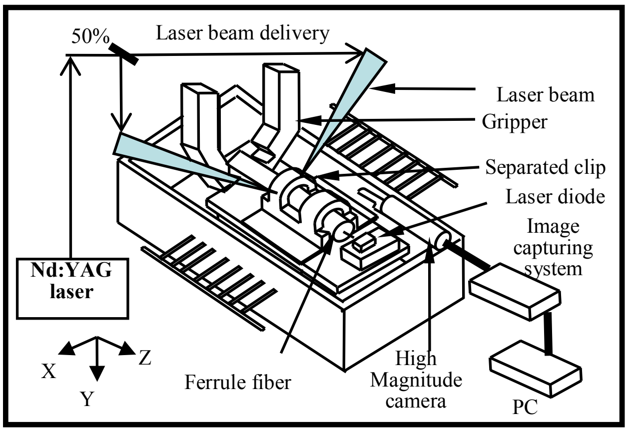

Fig. 1 Schematic diagram of butterfly type laser module packaging

2.2 Laser welding system

The laser welding system consisted of a 10W pulsed Nd: YAG laser, a dual-beam fiber optic beam delivery system, and an automatic control stage module (ACSM), as shown in Fig. 1. The dual-beam angle of incidences were accurately adjusted to $25^{o}\pm1^{o}$, the beam separation angles were set at 180^{o} apart, and the beam energy was balanced within ±2% of each other. The laser pulse settings of the Joules per pulse of 3 J, the spot size of laser beam at focus of 500 μm, and the surface to be welded held at the laser beam focus were used to weld the laser modules. The gripper of the laser welding system was used to hold the fiber ferrule in order to align the fiber with the laser diode[1-2].

2.3 High-magnification camera with image capturing system

A novel technique employing a high-magnification camera with image capturing system (HMCICS) was used to measure and compensate for the PWS induced fiber alignment shifts in butterfly type laser module packages. The HMCICS consisted of a 230x high-magnification video camera, a high-performance image capture card, and a computer, as shown Fig. 1. The optical signal generated by the image displacement was converted into a digital electronic signal. After data processing, such as linearization and averaging in software analyses, the measurement results were displayed. The HMCIAS technique used in this study had a 50 nm resolution, and enabled a real time measurement and compensation of the PWS direction and magnitude during the packaging of the laser-welded laser module[1-2].

2.4 Experimental Procedures

In general, the fiber alignment shifts due to PWS in laser-welded laser modules is a three-dimensional movements and may be described as translation and rotation displacements between the laser diode and the fiber axes. Since the center of the fiber ferrule in a butterfly-type laser module package is the fiber axis, the approach for measuring the alignment shifts due to the PWS is equivalent to probing the displacement of the center of the fiber ferrule, thus to probe the position and angle changes of such fiber ferrules. The position and angle changes of the fiber ferrule can be described by the change of vectors of vector FG, where F and G are the center of fiber tip and gripper, respectively. Since the position of the gripper was fixed during the welding process, the position needed to be measured was that of the fiber tip. A schematic diagram of PWS for translation of the fiber tip F. During the laser welding process, the position of the fiber tip may move from $F_0(x_0, y_0, z_0)$ to $F_1(x_1, y_1, z_1)$ where $F_0(x_0, y_0, z_0)$ and $F_1(x_1, y_1, z_1)$ are the coordinates of the fiber tip before and after welding, respectively, as shown in Fig.3 (a). The coordinates of $F_0(x_0, z_0)$ and $F_1(x_1, z_1)$ can be obtained by the HMCICS system as the high-magnification camera is aligned along the Y-axis. In order to measure the fiber shift in the Y-axis, the coordinate system X'Y'Z' is introduced by rotating the camera 15^o along the Z-axis, as shown in Fig.3 (b). New coordinates for $F_0(x_0, z_0')$ and $F_1(x_1, z_1')$ can be obtained by using the HMCICS. Then through $y_1 - y_0$, the displacement of the fiber tip in the Y-direction after welding can be calculated. Therefore, by comparing the position vector of the fiber ferrule before and after the laser welding, the PWS can be determined[1-2].

3. Postweld-shift measurements

3.1 The PWS Measurements

The coupling efficiency is as a function of X, Y, and Z directions. It indicated that the coupling efficiency of the 1.55 μm laser module was least sensitive along the optical axis of the Z direction, and most sensitive in the X and Y directions.

In this work, the translation in Y-axis may be considered as the most important factor for compensating for the PWS induced fiber alignment shifts. The schematic diagram for describing the position of the fiber ferrule is shown in Figs.3 (a) and (b). In this case, the position vector of the fiber tip moves from (x_0,y_0,z_0) to (x_1,y_1,z_1) in the XYZ coordinate, where the (x_0,y_0,z_0) and (x_1,y_1,z_1) are the center of fiber tip before and after welding, respectively. The displacement of the ferrule fiber can be represented by the XYZ coordinates with three translations Δx, Δy, Δz and three rotations $\Delta\theta_x$, $\Delta\theta_y$, $\Delta\theta_z$, as shown in Figs.3 and 5. Since the PWS is not sensitive on $\Delta\theta_z$, as shown in Fig.4, the $\Delta\theta_z$ was neglected. Clearly, the PWS mechanism of the fiber tip includes two behaviors: the translations in XYZ coordinate through the magnitudes of Δx, Δy, and Δz and the rotations along X and Y-axis through the angles of $\Delta\theta_x$ and $\Delta\theta_y$. The rotation parameters $\Delta\theta_x$ and $\Delta\theta_y$ are the functions of the Δy and Δx, as shown in Figs.5 (a) and (b).

In this study, x_0, y_0, and z_0 were all zero for the simplification of measurements. The parameters of the Δx, Δy, Δz and $\Delta\theta_x$, $\Delta\theta_y$, and y_1 are thus given by using the following formula: [1-2]

$$\Delta x = x_1 - x_0 \quad (1)$$

$$\Delta z = z_1 - z_0 \quad (2)$$

$$\Delta\theta_x = \sin^{-1}(\Delta y/L) \quad (3)$$

$$y_1 = x_1\tan 15^o + (x_1' - x_1\sec 15^o)\csc 15^o \quad (4)$$

$$\Delta y = y_1 - y_0 \quad (5)$$

$$\Delta\theta_y = \sin^{-1}(\Delta y/L) \quad (6)$$

where L is the length of fiber ferrule, x_1 and x_1' are the coordinates of fiber tip in X and X'-axis after laser welding, respectively, and y_1 is the coordinate of fiber tip in Y-axis before and after laser welding, respectively. The parameters of the Δy and $\Delta\theta_y$ were obtained by rotating the camera 15^o along the Z-axis. Comparison with the position vector of the fiber ferrule before and after the laser welding process, the PWS can be determined. Therefore, the PWS induced fiber alignment shifts were quantitatively specified by the five geometrical parameters of the Δx, Δy, Δz, $\Delta\theta_x$, and $\Delta\theta_y$[1-2].

3.2 The PWS pre-compensations

The direction and magnitude of the fiber alignment shifts induced by the PWS in a laser-welded laser module packages were determined by five geometrical parameters: Δx, Δy, Δz, $\Delta\theta_x$, and $\Delta\theta_y$. This suggests that the PWS can be corrected by applying compensation to the negative direction and the magnitude of the fiber alignment shifts to compensate for the displacement. Comprehensive measurements of the effects of the PWS compensation on the parameters of the Δx, Δy and Δz showed that the effect of the PWS compensation on the Δx and Δz were smaller than on the Δy. This indicates that the Δy is the dominant factor, which determines the fiber alignment shifts induced by the PWS in the laser-welded 1.3 μm laser module packaging. Laser module packaged by the separated clips with 5 mm spacing in this study is completed by the quantitative pre-compensation based on seesaw effect in Y-axis was governed by [1-2]

$$\frac{L_D}{D} = \frac{L_{D1}}{D_1} \quad (7)$$

$$D_1 = \frac{D}{L_D} \times L_{D1} \quad (8)$$

The pre-Compensation shift D can be calculated by following the above two equations. The pre-compensation can reduce the PWS mostly.

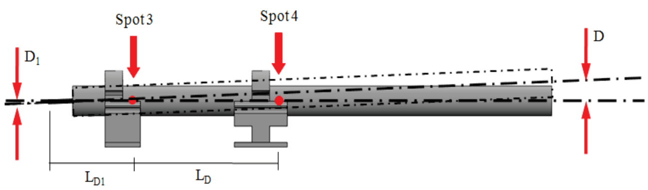

Fig. 2 The schematic of pre-compensation by separated clip

4. Results of PWS measurement and pre-compensation

Table shows the measured coupling power before welding, coupling power after welding, and recovery rate of coupling power compensated by pre-compensation shift. It clearly shows a high recovery rate on coupling power without post compensation.

Table 1 The measured coupling power before welding, coupling power after welding, and recovery rate of coupling power

Module number	Before welding (μW)	After welding (μW)	Recovery rate of coupling power (%)
1	1140	920	81
2	1050	990	94
3	1070	1090	102
4	1120	940	78

The result shows that the coupling efficiency of laser module packaged by the separated clips, with 5 mm spacing and pre-compensation between 19.5 μm to 21 μm in Y-direction, can be improved to relatively higher coupling efficiency. The experiment result also shows that the coupling efficiency can be improved to 78%-99% after laser welding packaging employing separated clips. In comparison to the previous clip on laser module packaging, separated clip can effectively minimize the PWS to avoid PWS compensation.

5. Discussion and conclusion

In summary, we have successfully demonstrated a novel technique by employing a high magnification image capturing system (HMCICS) to quantitatively measure and compensate for the effects of the PWS on the fiber alignment shifts in laser-welded butterfly-type laser module packages. The benefits of using the HMCICS technique to determine the fiber alignment shift were a 50 nm nanoscale resolution to overcome the submicron tolerance and qualitatively measure and compensate of the PWS direction and magnitude during the laser-welded butterfly-type laser module packages, when compared to the currently available qualitatively estimated techniques to compensate the PWS in butterfly-type laser module packages. When compared to the currently available qualitatively estimated techniques to correct the PWS[1-2], the PWS is mostly reduced and lead to the PWS compensation is negligible in the laser module packaging process. The result shows that the coupling efficiency of laser module packaged by the separated clips, with 5 mm spacing and pre-compensation between 19.5 μm to 21 μm in Y-direction, can be improved to relatively higher coupling efficiency. The experiment result also shows that the coupling efficiency can be improved to 78%-99% after laser welding packaging employing separated clips. In comparison to the previous clip on laser module packaging, separated clip can effectively minimize the PWS to avoid PWS compensation. Therefore, the reliable butterfly-type laser modules with high yield and high performance used in lightwave transmission systems may thus be developed and fabricated. [1-2].

Acknowledgments

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