

Laser Packaging System and Method

TECHNICAL FIELD

The present invention relates to the field of optoelectronic semiconductor devices and, in particular, to a system and method for sealing a glass package using a laser.

BACKGROUND

Optoelectronic semiconductor devices have been extensively used in all areas of our life, in which Organic Light Emitting Diodes (OLEDs) are promising in terms of application and are the focus of current research efforts thanks to their good color ratio, wide viewing angle, rapid response and other properties. However, electrodes and organic layers in OLED displays are vulnerable to oxygen and moisture, because penetration of these external substances may significantly shorten the service life of the devices. Therefore, it is important to provide OLED devices with effective hermetic sealing. Presented below are some difficulties in obtaining a suitable seal for an OLED device:

The hermetic seal should provide a barrier to oxygen (10^{-3} cm³/m²/day) and moisture (10^{-6} g/m²/day).

The hermetic seal should be sized as small as possible (e.g., less than 2mm) to avoid having a considerable effect on the size of the OLED display.

The temperature during sealing should not damage any component of the OLED display (e.g., electrodes and organic layers). For example, first pixels in the OLED display that are located about 1-2 mm away from the seal will fail when that temperature is 100 °C or higher;

Any gas released from the sealing process should not contaminate any material

in the OLED display.

The hermetic seal should allow encapsulation of point connections (e.g., thin-film chrome (Cr) electrodes) in the OLED display.

In recent years, a sealing method using laser heating of a glass frit has been used in the sealing of OLED displays, in which the glass frit has a low melting point and embodies a material having a high absorption rate for a specific light wavelength. A hermetic seal is formed between a glass cover on which the glass frit is disposed and a glass substrate on which an OLED is formed when the glass frit is heated and softened by a high-energy laser device. The glass frit is usually about 0.7-1 mm wide and 6-100 μm thick. Specifically, portions of a sealing line coated with the glass frit are consecutively irradiated by a controllable energy level produced by the laser device so that the glass frit is heated and softened to form the hermetic seal. However, this consecutive heating style may create a non-uniform temperature distribution in the glass frit (as shown in Fig. 1) which can lead to cracks, residual stresses or delamination therein and hence a defective or weak hermetic connection between the glass cover and the glass substrate. In addition, the method requires selection of major parameters for the sealing process, such as laser beam power and scanning speed. Restricted by this, the method is limited in terms of yield improvement.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a laser sealing system and method for sealing an OLED display or a glass package, which can solve the above-described non-uniform glass frit temperature distribution problem and allow a wide process window which is conducive to improving OLED display yield.

To this end, there is proposed herein a laser sealing system for sealing a glass package by heating a glass frit distributed along a predefined path in the glass

package, comprising: a controller module; a laser module which is coupled to the controller module and configured to generate a laser beam; and a laser scanning module which is coupled to both the controller module and the laser module and configured to project the laser beam generated by the laser module onto the glass frit, wherein the controller module is configured to control the laser scanning module in real time and to thereby control a scanning direction of the laser beam on the glass frit such that the laser beam scans the glass frit along the predefined path, and wherein the controller module is further configured to control in real time an output power of the laser module such that the generated laser beam has a power profile that matches the predefined path in real time.

Additionally, the laser sealing system may further comprise a temperature measurement module which is coupled to the controller module and configured to measure in real time a temperature at a surface location of the glass frit irradiated by the laser beam and to feed the measured temperature back to the controller module in real time.

Additionally, the temperature measurement module may be a pyrometer.

Additionally, the laser sealing system may further comprise a computer which is coupled to the controller module and configured to communicate data with the controller module.

Additionally, the controller module may be a single controller, a control system consisting of a plurality of controllers, or a control board integrated in the computer.

Additionally, the laser scanning module may be provided therein with a servo mechanism which is configured to alter a direction of the laser beam and change a speed and/or acceleration at which the laser beam scans the glass frit along the predefined path.

Also proposed herein is a laser sealing method for sealing a glass package by

heating a glass frit distributed along a predefined path in the glass package, comprising:

- activating a laser module so that the laser module generates a laser beam;

- activating a laser scanning module so that the laser scanning module projects the laser beam generated by the laser module onto the glass frit;

- controlling in real time, by the controller module, a direction in which the laser scanning module projects the laser beam onto the glass frit such that the laser beam scans the glass frit along the predefined path;

- controlling in real time, by the controller module, an output power of the laser module such that the generated laser beam has a power profile that matches the predefined path in real time; and

- causing the laser beam to scan the glass frit along the predefined path for a plurality of cycles until the glass frit is heated to its melting point.

Additionally, the predefined path may comprise one or more straight-line sections and one or more curved sections, wherein the power profile may comprise one or more straight-line section heating power profiles corresponding to the respective one or more straight-line sections and one or more curved section heating power profile corresponding to the respective one or more curved sections, and output powers associated with the straight-line section heating power profiles are different from output powers associated with the curved section heating power profiles.

Additionally, the plurality of scanning cycles may use a constant output power or output powers decreasing cycle by cycle of the laser module.

Additionally, laser sealing method may further comprise: using a temperature measurement module to obtain real-time temperature measurements on the surface of the glass frit and feed the measured temperature back to the controller module; and adjusting, by the controller module, at least one of the number of scanning cycles, the

output power of the laser module and the speed at which the laser beam scans the glass frit along the predefined path such that the temperature of the glass frit varies in accordance with a preset temperature profile.

Additionally, the speed at which the laser beam scans the glass frit along the predefined path may range from 1 m/s to 5 m/s.

Additionally, the laser scanning module may be activated prior to the activation of the laser module, wherein the laser module is activated after the laser scanning module becomes able to project the laser beam onto the glass frit with the laser beam moving at a predetermined speed along the predefined path.

Additionally, the laser sealing method may further comprise immediately deactivating the laser module after the glass frit has been heated to its melting point so that the glass frit cools naturally.

Additionally, the laser sealing method may further comprise, subsequent to the deactivation of the laser module, maintaining the operation of the laser scanning module for a further period of time and then deactivating it.

Additionally, the laser sealing method may further comprise, after the glass frit has been heated to its melting point, lowering the output power of the laser module to a predetermined value at which further scanning cycles are performed on the glass frit along the predefined path until the glass frit cools to a predetermined temperature.

Additionally, the laser sealing method may further comprise natural cooling of the glass frit after the glass frit has cooled to the predetermined temperature.

Additionally, in the laser sealing method, the laser module and the laser scanning module may be activated simultaneously, followed by gradually increasing the output power of the laser module, so that at the time when the laser scanning module becomes able to project the laser beam onto the glass frit with the laser beam moving at the predetermined speed along the predefined path, the output power of the

laser module reaches a predetermined value.

Additionally, the laser sealing method may further comprise, after the glass frit has been heated to its melting point, simultaneously adjusting the output power of the laser module and the speed at which the laser beam scans the glass frit along the predefined path such that the output power and the speed decrease to zero at the same time.

Compared to the prior art, the present invention majorly has the following benefits: the laser scanning module enables rapid periodic scanning of the glass frit by the laser beam, allowing the glass frit to be heated in a substantially uniform and synchronous manner and hence resulting in an improvement in the non-uniform temperature distribution problem arising from use of the conventional sealing method; and in the proposed laser sealing method, the laser module can produce a laser beam with a predefined power profile based on which heating of the glass frit is controllable.

In addition, the additional temperature measurement module is capable of obtaining and feeding back real-time temperature measurements on the surface of the glass frit. This enables the glass frit to be heated or cooled in a predefined fashion so that its temperature rises or decreases according to a predefined temperature profile.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a temperature vs. time profile of a glass frit whose portions are heated consecutively according to the prior art.

Fig. 2 is a top view of an OLED display sealed with the glass frit.

Fig. 3 shows modules of a laser sealing system according to a first embodiment of the present invention.

Fig. 4 schematically illustrates a laser scanning path for sealing an OLED

display using a glass frit in accordance with the first embodiment of the present invention.

Fig. 5 shows a predefined power profile used in a single scanning cycle in accordance with the first embodiment of the present invention.

Figs. 6A- 6B show simulated curves illustrating how the scanning speed and laser beam power affect the temperature of the glass frit in accordance with the first embodiment of the present invention.

Fig. 7 schematically illustrates a first manner in which a laser scanning module synchronously controls output of the laser beam in start and finish sections in accordance with the first embodiment of the present invention.

Fig. 8 shows modules of a laser sealing system according to a second embodiment of the present invention.

Fig. 9 is a structural schematic illustration of the laser sealing system according to the second embodiment of the present invention.

Fig. 10 schematically illustrates a second manner in which the laser scanning module synchronously controls output of the laser beam in the start and finish sections in accordance with the second embodiment of the present invention.

Fig. 11 shows predefined temperature rise and cooling profiles in accordance with the second embodiment of the present invention.

Fig. 12 shows a temperature vs. time profile of the glass frit that is heated using the laser sealing system and method according to the first or second embodiment of the present invention.

DETAILED DESCRIPTION

Systems and methods for sealing a glass package by laser scanning according to the present invention will be described in greater detail in the following description

which presents preferred embodiments of the invention and is to be read in conjunction with the accompanying drawings. It is to be appreciated that those of skill in the art can make changes to the invention disclosed herein while still obtaining the beneficial results thereof. Therefore, the following description shall be construed as being intended to be widely known by those skilled in the art rather than as limiting the invention.

For simplicity and clarity of illustration, not all features of the disclosed specific embodiment are described. Additionally, description and details of well-known functions and structures are omitted to avoid unnecessarily obscuring the invention. The development of any specific embodiment of the present invention includes specific decisions made to achieve the developer's specific goals, such as compliance with system-related and business-related constraints, which will vary from one implementation to another. Moreover, such a development effort might be complex and time consuming but would nevertheless be a routine undertaking for those of ordinary skill in the art.

The present invention will be further described in the following paragraphs by way of examples with reference to the accompanying drawing. Features and advantages of the invention will be more apparent from the following detailed description, and from the appended claims. Note that the accompanying drawings are provided in a very simplified form not necessarily presented to scale, with the only intention of facilitating convenience and clarity in explaining a few illustrative examples of the invention.

EMBODIMENT 1

Referring to Figs. 2 and 3, in this Embodiment, there is proposed a laser sealing system for forming a hermetic seal for an OLED display 120 with a glass frit. The

OLED display 120 is a typical glass package and comprises essentially a glass cover 121, a glass frit 122, a glass substrate 123, an OLED layer 125 and a plurality of electrodes 124. The glass frit 122 is disposed on the glass substrate 123 in the OLED display 120 of which a cross-sectional view is shown in Fig. 3 and a top view is illustrated in Fig. 2. The glass frit 122 may be pre-cured on the glass substrate 123 by screen printing and pre-sintering to form a sealing line having a certain thickness and assuming an oblong shape. Disposed on the glass substrate 123 are the OLED layer 125 that is internal to the sealing line of the glass frit 122 and the plurality of electrodes 124 for connecting to internal and external circuitry.

In this Embodiment, the laser sealing system comprises a controller module 201, a laser module 202 and a laser scanning module 203. The controller module 201 is coupled to both the laser module 202 and the laser scanning module 203 so as to control these modules. The laser module 202 is coupled to the laser scanning module 203 and is configured to generate a laser beam and deliver the laser beam to the laser scanning module 203 at a predefined power. The laser scanning module 203 is configured to change the propagation direction and movement characteristics of the laser beam 100. The system further comprises a computer 200 which is coupled to the controller module 201 for data exchange therewith.

The controller module 201 may be implemented as a single controller, a control system consisting of a plurality of controllers, or a control board integrated in the computer 200.

In this Embodiment, the laser scanning module 203 may be a scanning galvanometer. The laser scanning module 203 includes a servo mechanism (not shown) which is able to change the propagation direction of the laser beam so that the beam is deflected relative to a certain fixed axis in space by an angle θ that is within a maximum limit. The direction to which and the angle θ by which the laser beam 100

is deflected are controllable and determined by a rule indicated by a control signal transmitted by the controller module 201 to the laser scanning module 203. The servo mechanism is capable of rapidly and accurately altering the deflection of the laser beam 100 and controlling characteristics of the deflection of laser beam 100 during scanning, such as its angular velocity and angular acceleration, under the effect of the control signal. The laser scanning module 203 projects the laser beam 100 onto the glass frit 122 so that a light spot 110 of a specific shape and size is formed on the surface of the glass frit 122.

The laser module 202 can generate a laser beam 100 of a specific wavelength and deliver the energy of the laser beam 100 to the laser scanning module 203 at a predetermined power. The energy of the laser beam 100 delivered at the predefined power is adjustable in real time, and the energy adjustment of laser beam 100 as well as the activation and deactivation of laser beam delivery, is determined by a control signal sent by the controller module 201 to the laser module 202.

The controller module 201 is capable of synchronous control over the laser module 202 and the laser scanning module 203 so that the activation and deactivation of the output of laser beam 100 as well as laser beam power adjustment in the laser module 201 can be compatible with the operation of the servo mechanism in the laser scanning module 203. Alternatively, the controller module 201 may control the laser module 202 with a higher resolution compared to a resolution at which it controls the laser scanning module 203 while still entailing a compatible manner. Data may be communicated between the controller module 201 and the computer 200. Specifically, the controller module 201 can receive movement path, speed profile, power profile, time delay, target temperature, activation, deactivation and other information from the computer 200 and transfer information about the operating states of the various modules and the like to the computer.

In another aspect of this Embodiment, there is also proposed a laser sealing method using the above-described system and comprising the steps of:

S100: the controller module 201 controlling the laser module 202 such that the laser module 202 emits a laser beam 100 with a predefined power profile; and

S200: the controller module 201 controlling the laser scanning module 203 such that the laser beam 100 is projected by the laser scanning module 203 onto the glass frit 122 and periodically scans the glass frit 122 along a predefined path at a predetermined speed until the glass frit is heated to its melting point and forms a hermetic seal.

Specifically, the laser module 202 and the laser scanning module 203 are controlled to enable the laser beam 100 with the predefined power to be projected onto the glass frit 122 and scan along the pattern of the glass frit 122 (i.e., the sealing line) at a high speed, i.e., along the path indicated by the arrows in Fig. 4. The speed may range from 1 m/s to 5 m/s such as, for example, 3 m/s. At the beginning of the scanning, the laser beam 100 is irradiated onto the point a2 on the glass frit 122 to form a light spot 110 of a specific shape and size, as shown in Fig. 4. A scanning cycle is defined as a period of time in which the laser beam scans along the pattern and returns to the point a2. The point a2 is merely an example, and the start point of the scanning cycle is not limited thereto. In each scanning cycle, while different portions of the glass frit 122 absorb the energy of the laser beam and are thereby heated successively, as the scanning speed is rather fast, it can be considered that different portions of the glass frit on the sealing line are heated substantially simultaneously. In general, one scanning cycle cannot provide the glass frit 122 with sufficient energy to form a hermetic sealing connection between the two glass substrates 121 and 123.

In each scanning cycle, the controller module 201 controls the laser module

202 and the laser scanning module 203 (referred to hereinafter and in the figures as the “scanning galvanometer” or simply “galvanometer”) so that the laser beam 100 is moved in synchronization with its power adjustment. According, but not limited, to the predefined power profile shown in Fig. 5, the laser beam power varies linearly or non-linearly across each of the predetermined sections b1-b2, c1-c2, d1-d2 and e1-e2. As can be seen from Fig. 4, the sections b1-b2, c1-c2, d1-d2 and e1-e2 correspond to the respective corners of the oblong which require less energy compared to the remaining straight-line sections. Therefore, less power may be applied during the scanning of these curved corner sections. That is, the predefined power profile consists of linear section heating power segments corresponding to the respective straight-line sections scanned by the laser beam 100 and curved section heating power segments corresponding to the respective corners scanned by the laser beam 100. The two types of segments correspond to different power levels which allow the glass frit 122 on the sealing line to be heated overall uniformly.

The laser module and the galvanometer may be controlled to make the laser beam 100 repeat the aforementioned scanning cycle. The glass frit 122 may obtain sufficient energy from the multiple scanning cycles to provide a hermetic sealing connection between the glass substrates 121 and 123. After completing a first scanning cycle by the laser beam 100, the next scanning cycles may be carried out with the same power level or with distinct power levels resulting in gradually decreasing temperature increments cycle by cycle. In the latter case, the glass frit 122 may be heated with a temperature profile have gradually decreasing temperature increments, and the number of scanning cycles may be accordingly increased to achieve the target temperature. Alternatively, each scanning cycle may be associated with a distinct power profile.

Reference is now made to Figs. 6A and 6B. Fig. 6A shows temperature rise

curves of identical 0.3-meter long glass frits 122 across 10 scanning cycles ($n=10$) carried out with the same laser beam power p of 400 W, in which the curve a corresponds to a scanning speed v of 3 m/s, and curve b corresponds to a scanning speed of 1 m/s. As can be seen from the figure, the great difference between the scanning speeds leads to very different temperature profiles. In Fig. 6B, the curves 1, 2 and 3 show temperature profiles obtained by scanning processes carried out at the same number n of scanning cycles, the same scanning speed v and different laser beam power levels p , while the curve 4 illustrates a temperature profile resulting from a scanning process performed at the same power p , a different speed v and a different number n of scanning cycles. Thus, as can be seen from Figs. 6A and 6B, a suitable temperature profile can be achieved through adjusting the three parameters, i.e., the number of scanning cycles, the scanning speed and the laser beam power.

After the scanning cycle in which the glass frit 122 along the sealing line has absorbed sufficient energy (i.e., having reached the target temperature), the glass frit 122 is cooled. The cooling may be accomplished in either of two ways. One way is natural cooling in which the laser beam output is ceased to allow the glass frit 122 to cool naturally. Compared to the cooling in the conventional consecutive heating method, as the glass frit 122 along the sealing line is heated uniformly, it naturally cools in a more relaxed manner. The other way is to scan the glass frit at a lower power level compared to that at which it is heated until its temperature drops to a predetermined value. That is, after the completion of the heating process, further scanning cycles are performed on the glass frit 122 according to a predefined power profile with lower laser beam power levels so that the glass frit 122 is cooled with its temperature following an expected curve. In this way, the obtained cooling curve proceeds in a relaxed fashion without significant temperature drops, allowing good thermal stress properties. In addition, the second cooling method may be applied

either throughout the whole cooling process of the glass frit 122 or only to portion(s) of the natural cooling process in which the glass frit 122 cools relatively rapidly. In the latter case, the glass frit 122 is allowed to cool naturally without being heated in the rest of the process.

In the sections where the laser beam scanning is started and finished, an optimized control method may be performed. In one optimization method, in the start section such as, for example, the section a1-a2 in Fig. 4, the galvanometer is driven to move with the output of the laser beam not being activated such that the internal servo mechanism of the galvanometer has made the galvanometer move in the predefined path at a desired speed before the point a2 is reached. As such, when the laser beam is then activated at the point a2, the laser beam 100 is moving in the predefined path at the desired speed. With all the scanning cycles having been completed, the laser beam output is deactivated at the point a2, followed by the internal servo mechanism of the galvanometer making the galvanometer maintain the movement in the predefined path and at the desired speed for a period of time and being turned off thereafter at the point a3, as shown in Fig. 7.

EMBODIMENT 2

With reference to Fig. 8, a laser sealing system according to this Embodiment differs from that of Embodiment 1 in further including a temperature measurement module 204 which is coupled to the controller module 201 and configured to measure in real time a temperature at a surface location of the glass frit 122 where the light spot 110 is formed by the laser beam 100 irradiation. The real-time measurement may be accomplished in a contactless manner by the temperature measurement module 204, and the results are fed back to the controller module 201. The temperature measurement module 204 is characterized in that, even when the light spot 110 is moving at a high speed, it is still able to measure the temperature at the location of

the glass frit 122 where the light spot 110 is formed with a sufficient temporal/spatial resolution. The controller module 201 is capable of acquiring and processing temperature signals fed back by the temperature measurement module 204 and forms a closed control loop with the laser module 202 via control signals. The closed control loop may have a control resolution that is consistent with or higher than the control resolution of the laser scanning module 203.

Referring to Fig. 9, the proposed system for sealing a glass package by laser scanning comprises a computer 210, a controller 220, a laser 250, a scanning galvanometer unit 230 and a pyrometer 240, i.e., the temperature measurement module.

Accordingly, a laser sealing method according to this Embodiment differs from that of Embodiment 1 in that:

it allows the glass frit 122 to be heated in a predefined manner so that its temperature rise follows a predefined temperature profile and to be cooled in another predefined manner so that its temperature decreases according to another predefined temperature profile.

Specifically, in each scanning cycle, the controller 220 controls the laser 250 and the galvanometer 230 so that the laser beam 100 is moved in synchronization with its power adjustment. The pyrometer 240 measures in real time the temperature at the location where the light spot 110 is formed by the laser beam 100. The controller 220 acquires the temperature information fed back by the pyrometer 240, compares the temperature with a predetermined target temperature and performs necessary calculations, and carries out real-time control over the laser beam power based on the comparison. This closed-loop control over the temperature of the glass frit 122 allows each portion of the glass frit 122 on the sealing line to obtain energy and achieve the target temperature overall uniformly. Fig. 11 shows a temperature

curve with a section a-b corresponding to the process of the temperature of the glass frit 122 following the predetermined temperature profile enabled by the temperature feedback control and reaching the target temperature.

Similarly, after the scanning cycle in which the glass frit along the sealing line has absorbed sufficient energy (i.e., having reached the target temperature), the glass frit is cooled. The cooling may be accomplished by repeated scanning cycles over the glass frit 122 with lower laser beam power level(s) under the temperature feedback control so that the glass frit 122 cools according to a predetermined cooling profile such as, for example, the section b-c of the temperature curve of Fig. 11. This cooling method may be applied either throughout the whole cooling process of the glass frit 122 or only to portion(s) of a natural cooling process in which the glass frit 122 cools relatively rapidly. In the latter case, the glass frit 122 is allowed to cool naturally without being heated in the rest of the process, exemplified as the section c-d of the temperature curve of Fig. 11.

In the sections where the laser beam scanning is started and finished, another optimization method may be used, in which, initially, the galvanometer is moved and the laser beam is output simultaneously at the point a1. The output laser beam power is then controlled to rise from a low level. When the point a2 is reached, the power level climbs to the predefined value. At this point, the galvanometer begins to move in the desired way, followed by performance of normal scanning cycles. At the end of the process, the output laser beam power is adjusted to gradually decrease at the point a2, and the output of the laser beam and the movement of the galvanometer are stopped at the same time at the point a3. Fig. 10 shows a curve specifically illustrating the whole process.

With the proposed laser sealing system and method according to this Embodiment, uniform heating is achievable, as indicated by the temperature

distribution shown in Fig. 12. Compared to the conventional method in which glass frit portions are processed consecutively along the sealing line, the proposed laser sealing system and method allow the glass frit 122 to have a more uniform temperature distribution, as well as a more uniform spatial temperature distribution as proven by the spatial scan results.

In addition, the subject matter of the present invention allows a wider process window which is conducive to the improvement of OLED display yield. With the manufacture of 4.3 inch OLED displays as an example, the length needed to be sealed by the glass frit is about 0.3m. So, when the conventional method is used, in which a maximum scanning speed is about 20 mm/s due to process limitations, the sealing would take at least about 15 seconds. In contrast, with the method according to the present invention, the wider process window (i.e., selectable number of scanning cycles, laser beam power and scanning speed) allows the scanning speed and laser beam power to be increased to 300 mm/s or higher and 200 W or higher, respectively, resulting in a significant improvement in sealing efficiency.

In the subject matter of the present invention, as the temperature across the glass frit 122 along the sealing line varies substantially uniformly and synchronously, it is possible to approximately control the temperature rise and cooling profiles of the glass frit 122 through adjusting the number of scanning cycles, laser beam power levels or scanning speeds in respective scanning cycles, thereby enabling the control over the glass frit 122 according to the temperature rise and cooling profiles that cannot be achieved by the conventional method.

Further, the subject matter of the present invention can meet the requirements of hermetic sealing for OLED displays and can address the issues arising from the laser sealing of OLED displays, for example, sealing of the start and finish sections.

In summary, in the laser sealing systems and methods according to the

foregoing Embodiments, the laser scanning module enables rapid periodic scanning of the glass frit by the laser beam, allowing the glass frit to be heated in a substantially uniform and synchronous manner and hence resulting in an improvement in the non-uniform temperature distribution problem arising from use of the conventional packaging method. In the proposed methods, the laser module can produce a laser beam with a predefined power profile based on which heating of the glass frit is controllable.

Furthermore, the additional temperature measurement module is capable of obtaining and feeding back real-time temperature measurements on the surface of the glass frit. This enables the glass frit to be heated or cooled in a predefined fashion so that its temperature rises or decreases according to a predefined temperature profile.

The foregoing description presents merely preferred embodiment examples of the present invention and does not limit the scope of the invention in any sense. All equivalent substitutions or modifications made to the subject matter disclosed herein by those of ordinary skill in the art without departing from the scope of the present invention fall within the scope of the invention.

CLAIMS

1. A laser sealing method for sealing a glass package by heating a glass frit distributed along a predefined path in the glass package, comprising:

activating a laser module so that the laser module generates a laser beam;

activating a laser scanning module so that the laser scanning module projects the laser beam generated by the laser module onto the glass frit;

controlling in real time, by a controller module, a direction in which the laser scanning module projects the laser beam onto the glass frit such that the laser beam scans the glass frit along the predefined path;

controlling in real time, by the controller module, an output power of the laser module such that the generated laser beam has a power profile that matches the predefined path in real time; and

causing the laser beam to scan the glass frit along the predefined path for a plurality of cycles until the glass frit is heated to a melting point thereof,

wherein the laser scanning module is activated prior to the activation of the laser module, and wherein the laser module is activated after the laser scanning module becomes able to project the laser beam onto the glass frit with the laser beam moving at a predetermined speed along the predefined path.

2. The laser sealing method of claim 1, wherein the predefined path comprises one or more straight-line sections and one or more curved sections, wherein the power profile comprises one or more straight-line section heating power profiles corresponding to the respective one or more straight-line sections and one or more curved section heating power profiles corresponding to the respective one or more curved sections, and wherein output powers associated with the straight-line section heating power profiles are different from output powers associated with the curved section heating power profiles.

3. The laser sealing method of claim 1, wherein the plurality of cycles of scanning use a constant output power of the laser module or output powers decreasing cycle by cycle of the laser module.

4. The laser sealing method of claim 1, further comprising: using a temperature measurement module to obtain real-time temperature measurements on a surface of the glass frit and feed the measured temperature back to the controller module; and adjusting, by the controller module, at least one of a number of scanning cycles, the output power of the laser module and the speed at which the laser beam scans the glass frit along the predefined path such that a temperature of the glass frit varies in accordance with a preset temperature profile.

5. The laser sealing method of claim 4, wherein the speed at which the laser beam scans the glass frit along the predefined path ranges from 1 m/s to 5 m/s.

6. The laser sealing method of claim 1, further comprising immediately deactivating the laser module after the glass frit has been heated to the melting point thereof so that the glass frit cools naturally.

7. The laser sealing method of claim 6, further comprising, subsequent to the deactivation of the laser module, maintaining an operation of the laser scanning module for a further period of time and then deactivating the laser scanning module.

8. The laser sealing method of claim 1, further comprising, after the glass frit has been heated to the melting point thereof, lowering the output power of the laser module to a predetermined value at which further scanning cycles are performed on the glass frit along the predefined path until the glass frit cools to a predetermined temperature.

9. The laser sealing method of claim 8, further comprising, after the glass frit has cooled to the predetermined temperature, natural cooling of the glass frit.

10. The laser sealing method of claim 1, wherein the laser module and the laser scanning module are activated simultaneously, followed by gradually increasing the output power of the laser module, such that at the time when the laser scanning module becomes able to project the laser beam onto the glass frit with the laser beam moving at a predetermined speed along the predefined path, the output power of the laser module reaches a predetermined value.

11. The laser sealing method of claim 10, further comprising, after the glass frit has been heated to its melting point, simultaneously adjusting the output power of the laser module and the speed at which the laser beam scans the glass frit along the predefined path such that the output power and the speed gradually decrease to zero at the same time.