Title: SUBSTRATE CONNECTION BY HEAT ACTIVATED BINDER

Abstract: The present invention relates to a method and an apparatus (100) for connecting two substrates (12, 13) by an intermediate body (11) of a heat-activated binder, for example a frit. The binder body is locally heated above its activation temperature, which may preferably be achieved by a laser light beam (L). The subsequent cooling down is done such that, seen in a cross section through the binder body, there is always only a single region (11c) where temperature has already dropped below the curing temperature. Hence it is avoided that local binding between the two substrates occurs at two separate positions between which the substrates are still unconnected.

FIG. 1
— as to applicant’s entitlement to apply for and be granted a patent (Rule 4.17(iii))

Published:
— with international search report (Art. 21(3))

— before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))
FIELD OF THE INVENTION

The invention relates to a method and an apparatus for connecting two substrates by an intermediate heat-activated binder, for example a frit. Moreover, it relates to an optoelectronic device, particularly an OLED, that is produced by such a method.

BACKGROUND OF THE INVENTION

The US 2009-0221207 A1 discloses a procedure for connecting two glass substrates via a frit that is heated above its melting temperature with a laser light beam. In view of the use of materials that have largely different coefficients of thermal expansion, the irradiation with the laser light beam is started and ended according to a particular power switching schedule. Thus the later occurrence of cracks in the connected substrates shall be avoided.

SUMMARY OF THE INVENTION

Based on this background it was an object of the present invention to provide improved means for connecting two substrates by a heat-activated binder, wherein it is desirable that also low-cost substrates can be processed.

This object is achieved by a method according to claim 1, an apparatus according to claim 2, and an optoelectronic device according to claim 10. Preferred embodiments are disclosed in the dependent claims.

According to its first aspect, the invention relates to a method for connecting two substrates, wherein the term "substrate" shall denote any solid body of a (homogeneous or inhomogeneous) material that may serve as a carrier of further components. Typical examples of substrates are plates of glass or (transparent) plastic. The method comprises the following steps:

- Deposition of a body of the heat-activated binder between the substrates. The binder body will typically have a filamentous shape with an extension in
longitudinal direction that is much larger than its extension in transversal direction. The term "heat-activated binder" shall mean that bonding of the binder to a substrate will (only) start if the binder temperature rises above a given characteristic temperature, which is called "activation temperature" in the following. The binder may for example (partially) melt at the activation temperature, or a chemical reaction may be initiated. Moreover, the temperature of the binder must drop after activation below a second characteristic temperature, called "curing temperature" in the following, to make the bonds to the substrates become permanent or fixed. The curing temperature may have the same value as the activation temperature; both the activation and the curing temperature may for example correspond to the melting or softening point of the binder.

- Heating of the aforementioned binder body at least locally above the activation temperature of the binder and thereafter letting it cool down again in such a way that, seen in a (predetermined) cross section from one border to the opposite border of the binder body, there is always only a single (connected) region in which temperature has already dropped below the curing temperature of the binder. This means that, during cooling down and in a given cross section through the binder body, there are never two separate points at which the temperature is already below the curing temperature (after having been above the activation temperature) while temperature at the position between them is still above the curing temperature. It should be noted that the heating (and cooling down) of the binder body is preferably "local" in such a sense that it takes place completely across a transversal extension of the binder body but only partially along its longitudinal extension. If the binder body is oblong, the considered "cross section from one border to the opposite border of the binder body" is preferably directed in transversal direction, i.e. at an angle between about 70° and about 110° with respect to the local longitudinal axis of the binder body.

According to a second aspect, the invention relates to an apparatus for connecting two substrates via a body of a heat-activated binder disposed between the substrates, said apparatus comprising a heating device with which the above method can be executed. In particular, the heating device is designed such that it can at least locally heat up the binder body above its activation temperature and then let it cool down again in such a way that, in a cross section through the binder body, the region in which temperature has dropped below the curing temperature is always a single, connected region.

The method and the apparatus described above have the unique feature of implementing a particular, favorable temperature course across the body of the binder material. This course is such that there are never two unconnected regions at which bonding
between the substrates is already permanent (because temperature has dropped below the
curing temperature) while it is not yet permanent at intermediate points. The inventors have
observed that the latter situation is often the cause of tension and cracks occurring in the
substrates when the intermediate region cures. Avoid this situation therefore prevents such
defects and provides better production results.

In the following, different embodiments of the invention will be described that relate to both the method and the apparatus described above.

A first particular embodiment is related to the cooling down phase. It is characterized in that temperature drops below the curing temperature first in an inner region of the binder body. This means that the region where the curing temperature is first reached (from higher temperatures) is sandwiched in a cross section through the binder body between regions that are still hotter than the curing temperature. During cooling down, this initial region will gradually grow until it reaches the lateral borders of the binder body. In contrast to a cooling process that starts at one lateral border of the binder body and then proceeds through the binder body, the proposed cooling process that starts in an inner region often yields more stable binding structures.

In general, heating of the binder above its activation temperature may be done in many different ways. In a preferred embodiment, the heating is achieved by irradiating the binder body with a light beam, i.e. absorption of the light by the binder provides the energy for heating the binder up. Most preferably, a laser light beam is used for this purpose. Heating with a light beam is a favorable procedure because it can be done in a contactless manner, it can readily be controlled, and it can be spatially limited to regions where heating is desired.

In a preferred embodiment of the aforementioned approach, the light beam is moved along the binder body. Thus it is possible to sequentially heat up an extended structure of the binder body with a light beam of limited cross section. Moreover, particular temporal heating courses can be established in this way within the binder body. The light beam may have a constant shape and/or intensity profile throughout the movement, or its shape and/or intensity profile may temporally vary according to the heating requirements in different sections of the binder body (straight sections, bends, crossings of electrical leads etc.).

The light beam that is used for heating the binder may particularly have a substantially C-shaped cross section. In this context, a "C-shape" shall comprise any shape of two lines or arcs that meet at an angle, thus for example also comprising shapes that resemble a "V". When such a C-shaped light beam is moved along an oblong binder body with the central part of the C-shape ahead (i.e. the open end of the C being on the side opposite to the
movement direction), central regions of the binder body will be reached first but also be left first by the light beam in comparison to regions lying laterally in transversal direction. As a consequence, the central regions will start to cool down prior to their neighboring peripheral regions. The central regions of the binder body will therefore first reach the curing temperature, and cooling spreads from them in transversal direction towards the lateral borders.

The aforementioned C-shaped light beam may be generated in different ways, for example with appropriate optics. In a preferred embodiment of the invention, a light beam of an arbitrary cross section (e.g. a circular cross section) is oscillated or wobbled (e.g. using a set of x,y-galvo mirrors) across a substantially C-shaped irradiation zone. In this way a software controlled irradiation of a C-shaped region can be achieved without the need of dedicated optics. A further advantage of this approach is that the shape and/or the dimensions of the irradiated zone can readily be changed which is especially advantageous at corners.

According to a preferred embodiment of the aforementioned approach, the oscillating speed of the light beam is chosen high enough to keep the temperature drop which occurs at any position of the binder body between two consecutive passages of the light beam below 30 %, preferably below 10 %. This embodiment addresses the fact that points of the binder body in the C-shaped irradiation zone are not continuously reached by the light beam but only intermittently when the oscillating light beam passes by. During the intermediate "dark" times, the temperature at these points of the binder body will usually drop according to the local thermal decay time. If the oscillation speed is chosen high enough, such temperature drops can however be kept small, thus allowing a practically continuous heating up of the material in the C-shaped irradiation zone.

The two substrates that are connected by the binder body may be used for many different purposes and/or as parts of many different devices. Preferably, the substrates may accommodate an optoelectronic component, particularly an (organic or inorganic) electroluminescent component or a photosensitive component. The optoelectronic component is usually arranged between the two substrates that serve as a carrier and/or as a protective cover, wherein a tight connection between the substrates that seals the optoelectronic component from the environment is provided by the binder body.

In accordance with the aforementioned embodiment, the invention also relates to an optoelectronic device, particularly to an Organic Light Emitting Diode (OLED) or a solar panel, said optoelectronic device comprising two substrates between which an optoelectronic component (e.g. an electroluminescent layer) is arranged, the substrates being
connected and sealed by a binder body that was generated by a method of the kind described above.

In the following, various preferred embodiments will be described that relate to a method, an apparatus, and an optoelectronic device of the kind described above.

According to a first such embodiment, the binder that connects the two substrates is a frit. A frit has the advantage that it provides a firm bond between two (glass) substrates and that it can readily be heated by a suitable light beam. Examples of appropriate frit materials are described in the US 2007-0128966 A1, WO 2007-067533 A2, US 2006-0082298 A1, WO-2009045320 A2, and US 20090221207 A1.

At least one of the substrates may be transparent to allow the passage of light for heating up the binder. Preferably, at least one of the substrates comprises a glass, most preferably a soda-lime glass, which is comparatively low-cost and hence suitable for a use in a mass product. It is an advantage of the present invention that substrate materials can be chosen which do not optimally match the binder material, e.g. with respect to their coefficient of thermal expansion, because the method of the invention minimizes problems resulting from such differences.

The binder body may preferably encircle completely an inner region, in which further components can be arranged that are sealed from the environment.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects of the invention will be apparent from and elucidated with reference to the embodiment(s) described hereinafter. These embodiments will be described by way of example with the help of the accompanying drawings in which:

Fig. 1 schematically illustrates in a side view a method according to the present invention for connecting two substrates;

Fig. 2 schematically illustrates in a top view the irradiation of a binder body with a light beam oscillating in a C-shape.

Like reference numbers in the Figures refer to identical or similar components.
DETAILED DESCRIPTION OF EMBODIMENTS

Laser Frit Sealing can be used for hermetic OLED sealing without the need of a costly getter and cavity glass. While this procedure works for the connection of special substrates from borosilicate glass, a fully cost effective solution would need to work for commercially available (low cost) glass plates, particularly for soda-lime. However, problems like cracks in the glass are often observed when soda-lime glass plates are connected in a process of Laser Frit Sealing.

Figure 1 schematically illustrates in this context the method of connecting two substrates by an intermediate heat-activated binder. The Figure shows the following components:

- A (semifinished) OLED device 10 comprising a first substrate 12 and a second substrate 13 between which a binder body 11 and an optoelectronic component 14 are arranged. As known to a person skilled in the art, the optoelectronic component 14 may comprise an organic electroluminescent layer, electrode layers, and electrical leads. The binder material extends as a filamentous binder body 11 in longitudinal direction (y-direction, cf. Figure 2), having a cross section in transversal direction (x-direction). In the shown example, the binder 11 shall be a frit, i.e. the terms "binder" and "frit" will in the following be used as synonyms.

- An apparatus 100 with a heating device 20 for generating a laser light beam L that irradiates the binder 11 through the transparent upper substrate 13, thus heating the binder up above its "activation temperature", i.e. the melting or softening temperature of the frit. The heating device 20 comprises a light source 21 generating a primary laser light beam, and optics 22 for deflecting this light beam L in longitudinal (y) and transversal (x) direction. This deflection of the laser light beam is done under the control of a control unit 23, which is for example realized by a digital data processing unit with appropriate software.

If the laser light beam L would have a circular or rectangular cross section (in the xy-plane) covering the whole width (x-direction) of the binder body 11, it would uniformly heat up the whole transversal cross section. The inventors noted however that problems may occur with such a heating. In particular, they recognized that a root cause of stress build-up occurs during the cooling (re-solidification) of the molten frit 11: since the outer parts 11a, 11a’ of the frit 11 are exposed to a cold environment, these outer parts will solidify first (when their temperature drops below a "curing temperature") while the central part 11c of the frit is still hot and fluid. When the central part 11c then wants to shrink during cool-down, it is restrained by the already solidified outer parts 11a, 11a' of the frit.
In view of this, it is proposed here to avoid excessive tensile stress by heating the frit 11 in such a way that its central part 11c cools down first, followed by the outer parts 11a, 11a'. Or, expressed with different words, the (lateral) edges of the frit 11 should remain hotter than the center during cool-down.

The Figures illustrate one way to realize the aforementioned general concept by using a laser light beam L that moves not only in the longitudinal y-direction along the frit 11 but that also simultaneously oscillates or wobbles with a component in transversal x-direction such that it (effectively) irradiates a C- or V-shaped irradiation zone.

Figure 2 shows this in a top view onto the frit 11 extending in y-direction. The frit 11 is irradiated by a laser light beam L with circular cross section, which is oscillated with a comparatively large oscillation speed \( v_0 \) along a C-shaped irradiation zone extending in transversal direction. The oscillating behavior of the laser light beam L is generated by the deflection optics 22 illustrated in Figure 1, which is realized here by a set of x,y-galvo mirrors. Superimposed to the mainly transversal oscillating movement of the laser light beam L is a constant movement in longitudinal (y) direction with a (slower) movement speed \( v_y \).

When the oscillation speed \( v_0 \) is large in comparison to the thermal decay time within the frit 11, the oscillation across the C-shaped irradiation zone has the same effect as a continuous irradiation with a C-shaped laser light beam. In a typical example of the described apparatus 100, the radius \( r \) of the circular cross section of the light beam L is about 0.25 mm, the radius \( \Delta \) of the C-shaped irradiation zone is about 0.35 mm, the longitudinal movement velocity \( v_y \) is about 15 mm/s, and the power of the laser light beam is about 42 W. Moreover, a typical value of the oscillation speed \( v_0 \) is between about 300 mm/s and about 1000 mm/s.

The combined effect of the laser light beam L oscillating in the C-shaped irradiation zone and moving in longitudinal direction is that the frit material is heated above its melting temperature within a moving C-shaped irradiation zone. As a consequence, central regions 11c of the frit 11 are reached and left by the laser light beam L prior to their laterally neighboring regions 11a, 11a'. Seen in a transversal cross section, e.g. in the section along line I-I of Figure 2 that is shown in Figure 1, the curing temperature (i.e. the softening point at which the frit re-solidifies and stable bonds between the two substrates 12, 13 establish) is therefore first reached in a single, connected central region 11c. The cooling below the curing temperature then spreads and the central region grows in transversal direction towards the peripheral regions 11a, 11a'. At any time and in any transversal cross section, there will only be one single connected region in which the temperature is below the curing temperature and in which the substrates 12, 13 are already connected.
It should be noted that it would also be possible to start cooling at one (!) border of the frit 11, and to let it spread from there in transversal direction through the frit 11 to the opposite border. This could for example be achieved by using an appropriately shaped (e.g. substantially straight) moving irradiation zone that is slanted with respect to the longitudinal direction of the frit.

Moreover, there are numerous other ways to get a C-shaped laser intensity distribution on the work-piece, using for example special (diffractive) optics.

In summary, the present invention relates to a method and an apparatus 100 for connecting two substrates 12, 13 by an intermediate body 11 of a heat-activated binder, for example a frit. The binder body is locally heated above its activation temperature, which may preferably be achieved by a laser light beam L. The subsequent cooling down is done such that, seen in a cross section transversal through the binder body, there is always only a single region 11c where temperature has already dropped below the curing temperature. Hence it is avoided that local binding between the two substrates occurs at two separate positions between which the substrates are still unconnected. The invention can particularly be applied to the hermetic sealing of (opto-electronic) devices packaged using soda-lime glass such as OLED and solar devices.

Finally it is pointed out that in the present application the term "comprising" does not exclude other elements or steps, that "a" or "an" does not exclude a plurality, and that a single processor or other unit may fulfill the functions of several means. The invention resides in each and every novel characteristic feature and each and every combination of characteristic features. Moreover, reference signs in the claims shall not be construed as limiting their scope.
CLAIMS:

1. A method for connecting two substrates (12, 13), comprising
   - disposing a body (11) of a heat-activated binder between the substrates;
   - heating the binder at least locally above its activation temperature and
   letting it cool down again in such a way that, in a cross section through the binder body (11),
   there is always only a single region (1lc) in which temperature has dropped below the curing
   temperature of the binder.

2. An apparatus (100) for connecting two substrates (12, 13) by a body (11) of a
   heat-activated binder disposed between the substrates, comprising a heating device (20) for
   heating the binder at least locally above its activation temperature and letting it cool down
   again in such a way that, in a cross section through the binder body (11), there is always only
   a single region (1lc) in which temperature has dropped below the curing temperature of the binder.

3. The method according to claim 1 or the apparatus (100) according to claim 2,
   characterized in that, during cooling down, temperature drops below the curing temperature
   first in an inner region (1lc) of the binder body (11).

4. The method according to claim 1 or the apparatus (100) according to claim 2,
   characterized in that the heating of the binder body (11) is achieved by irradiating it with a
   light beam, preferably a laser light beam (L).

5. The method or the apparatus (100) according to claim 4,
   characterized in that the light beam (L) is moved along the binder body (11).

6. The method or the apparatus (100) according to claim 4,
   characterized in that the light beam (L) has a substantially C-shaped cross section.
7. The method or the apparatus (100) according to claim 4, characterized in that the light beam (L) is oscillated across a substantially C-shaped irradiation zone.

8. The method or the apparatus (100) according to claim 7, characterized in that the oscillation speed \( (v_0) \) is large enough to keep the temperature drop which occurs at a position of the binder body (11) between two passes of the light beam (L) below 30 \%, preferably below 10 \%.

9. The method according to claim 1 or the apparatus (100) according to claim 2, characterized in that the substrates (12, 13) accommodate an optoelectronic component (14), particularly an electroluminescent material or a photosensitive material.

10. An optoelectronic device, particularly an OLED (10) or a solar panel, comprising two substrates (12, 13) between which an optoelectronic component (14) is arranged, the substrates being connected and sealed by a binder body (11) in a method according to claim 1.

11. The method according to claim 1, the apparatus (100) according to claim 2, or the optoelectronic device (10) according to claim 10, characterized in that the binder is a frit (11).

12. The method according to claim 1, the apparatus (100) according to claim 2, or the optoelectronic device (10) according to claim 10, characterized in that at least one of the substrates (12, 13) comprises a glass, preferably a soda-lime glass.

13. The method according to claim 1, the apparatus (100) according to claim 2, or the optoelectronic device (10) according to claim 10, characterized in that the binder body (11) encircles an inner area.
A. CLASSIFICATION OF SUBJECT MATTER
INV. C03C27/06 H01L51/52
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
C03C H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal , WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<td>US 2009/086325 AI (LIU ANPING [US] ET AL) 2 April I 2009 (2009-04-02) abstract  figures 8,9 paragraphs [0002] , [0012], [0015], [0020], [0036], [0059] claims 1-20</td>
<td>1-6,9-13</td>
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* Special categories of cited documents :
  * "X" document defining the general state of the art which is not considered to be of particular relevance
  * "E" earlier document but published on or after the international filing date
  * "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
  * "O" document referring to an oral disclosure, use, exhibition or other means
  * "P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"A" document member of the same patent family

Date of the actual completion of the international search
18 March 2011

Date of mailing of the international search report
25/03/2011

Name and mailing address of the ISA/
European Patent Office, P. B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016

Authorized officer
Mertins, Frederic
### DOCUMENTS CONSIDERED TO BE RELEVANT

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### INTERNATIONAL SEARCH REPORT

**Box No. II  Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)**

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [ ] Claims Nos.: because they relate to subject matter not required to be searched by this Authority, namely:

2. [X] Claims Nos.: 1. 3-13 (all partly)
   because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
   
   **See further INFORMATION sheet PCT/ISA/21Q**

3. [ ] Claims Nos.: because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

### Box No. III  Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. [ ] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

**Remark on Protest**

[ ] The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

[ ] The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

[ ] No protest accompanied the payment of additional search fees.
Continuation of Box 11.2

Claims Nos.: 1, 3-13 (all partially)

Present claim 1 relates to an extremely large number of possible methods. Support and disclosure in the sense of Article 6 and 5 PCT is to be found however for only a very small proportion of the methods claimed, see the description on page 3, line 30 - page 4, line 13, on page 5, lines 6-10, on page 6, lines 1-7, lines 17-18 and lines 28-30, and on page 8, lines 15-17. The non-compliance with the substantive provisions is to such an extent, that the search was performed taking into consideration the non-compliance in determining the extent of the search of claim 1 (PCT Guidelines 9.19 and 9.23). The search of claim 1 was restricted to those claimed methods which appear to be supported, namely a method as defined in claim 1 of the present application with the two substrates being glass substrates, the binder being a glass frit and the step of heating and cooling the glass frit being disclosed from page 3, line 30 to page 4, line 6 in the description of the present application. A similar reasoning applies to the subject-matter of claims 3-13 since said claims 3-13 are (at least to a certain extent) dependent on claim 1.

The applicant's attention is drawn to the fact that claims relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EP0 policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure. If the application proceeds into the regional phase before the EP0, the applicant is reminded that a search may be carried out during examination before the EP0 (see EP0 Guideline C-VI, 8.2), should the problems which led to the Article 17(2) declaration be overcome.