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# Datasheet for the decision of 3 February 2015

**Case Number:** T 0358/11 - 3.4.03

**Application Number:** 05768282.5

**Publication Number:** 1782486

**IPC:** H01L51/00

**Language of the proceedings:** EN

**Title of invention:**
ORGAN DEVICES HAVING A FIBER STRUCTURE

**Applicant:**
THE TRUSTEES OF PRINCETON UNIVERSITY

**Headword:**

**Relevant legal provisions:**
EPC 1973 Art. 54(1), 56, 84

**Keyword:**
Inventive step (no)

**Decisions cited:**

**Catchword:**

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**Beschwerdekammern**
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**Case Number: T 0358/11 - 3.4.03**

# D E C I S I O N
# of Technical Board of Appeal 3.4.03
# of 3 February 2015

| | |
|---|---|
| **Appellant:** (Applicant) | THE TRUSTEES OF PRINCETON UNIVERSITY<br>P.O. Box 36<br>Princeton, NJ 08544 (US) |
| **Representative:** | Kiriczi, Sven Bernhard<br>Schneiders & Behrendt<br>Rechtsanwälte Patentanwälte<br>Mühlthaler Strasse 91c<br>81475 München (DE) |
| **Decision under appeal:** | **Decision of the Examining Division of the European Patent Office posted on 8 October 2010 refusing European patent application No. 05768282.5 pursuant to Article 97(2) EPC.** |

**Composition of the Board:**

| | |
|---|---|
| **Chairman** | G. Eliasson |
| **Members:** | R. Bekkering |
| | T. Bokor |

## Summary of Facts and Submissions

I. The appeal is against the refusal of application no. 05 768 282 for lack of clarity, Article 84 EPC (main request, first and fourth auxiliary request) and lack of novelty, Article 54(1) EPC (main request, first, second, third and fourth auxiliary request) over document

D2: WO 03/065471 A.

II. At oral proceedings before the board, the appellant requested that the decision under appeal be set aside and that a patent be granted on the basis of the following application documents:

*Main request:*

Claims 1 to 20 filed as "*Auxiliary request 1*" with letter of 22 April 2010;

*First auxiliary request:*

Claims 1 to 21 filed as "*Auxiliary request 1*" with the statement setting out the grounds of appeal of 4 February 2011;

*Second auxiliary request:*

Claims 1 to 21 filed as "*Auxiliary request 2*" with the statement setting out the grounds of appeal of 4 February 2011.

III. Reference is also made to the following documents:

D8: Stübinger T et al., "*Exciton diffusion and optical interference in organic donor-acceptor photovoltaic cells*", Journal of Applied Physics, Vol. 90, No. 7, 1 October 2001, pages 3632 to 3641,

D10: Peumans P et al., "*Efficient bulk heterojunction photovoltaic cells using small-molecular-weight organic thin films*", Nature, Vol. 425, 11 September 2003, pages 158 to 162.

IV. Claim 1 according to the main request reads as follows:

"*A photosensitive device structure (200), comprising:*
*a conductive core (202, 204) including a first electrode (204);*
*an organic layer (206) comprising a photoactive region for absorbing light to form an exciton for being dissociated at a heterojunction formed by the juxtaposition of an acceptor layer and a donor layer, wherein the thicknesses of the individual layers are within the characteristic diffusion length of the exciton, and wherein the organic layer (206) surrounds the core and is electrically connected to the first electrode; and*
*a transparent second electrode (208) surrounding and electrically connected to the organic layer (206).*"

V. Claim 1 according to the first auxiliary request corresponds to claim 1 of the main request, with the first feature reading as follows:

"*a conductive core (202, 204) including a first electrode (204), wherein the thickness of the first electrode (204) is greater than or equal to*

$$\frac{\rho_1 . L^2 . \Phi . \eta_{pwr}}{0.05 . FF^2 . V_{oc}^2}$$

*where $\rho_1$ is the resistivity of the first electrode, L is uninterrupted length of the photosensitive device structure, Φ is optical flux, $\eta_{pwr}$ is the device's power efficiency, FF is the fill factor, and $V_{oc}$ is open circuit voltage*".

VI. Claim 1 according to the second auxiliary request corresponds to claim 1 of the first auxiliary request, with the second feature reading as follows (added feature highlighted by the board):

"*an organic layer (206) comprising a photoactive region for absorbing light to form an exciton for being dissociated at a* ***bulk*** *heterojunction formed by the juxtaposition of an acceptor layer and a donor layer, wherein the thicknesses of the individual layers are within the characteristic diffusion length of the exciton, and wherein the organic layer (206) surrounds the core and is electrically connected to the first electrode*".

VII. The appellant submitted in substance the following arguments:

Contrary to what was held in the decision under appeal, it was clear what the exciton diffusion length was. Divergencies in the reported values of the exciton diffusion length for a given material were due to differences in purity, morphology and processing.

Moreover, the subject-matter of claim 1 of the main

request was both novel and inventive over the cited prior art. Document D2 related to dye-sensitized solar cells, which did not have the claimed donor and acceptor layers and did not involve the generation of excitons. Accordingly, there was nothing suggesting the claimed restrictions on the layer thicknesses. Moreover, the skilled person would not combine this document with document D8, since D8 did not concern the same type of device. Furthermore, D8 suggested layer thicknesses larger than the exciton diffusion length.

The subject-matter of claim 1 of the first auxiliary request was also both novel and inventive over the cited prior art. There was nothing suggesting the claimed expression for the thickness of the first electrode. In order to arrive at the expression, some assumptions had to be made which were not obvious to the skilled person.

Furthermore, also the subject-matter of claim 1 of the second auxiliary request was both novel and inventive over the cited prior art. Document D10 in fact led away from the claimed invention, the bulk heterojunction as presented in D10 making it unnecessary to put any restrictions on the thickness of the donor and acceptor layers as required by claim 1.

## Reasons for the Decision

1. The appeal is admissible.

*2. Main request*

*2.1 Amendments*

Claim 1 according to the main request is based on claims 1 and 13 as originally filed and on the description as originally filed (cf paragraphs [0043] and [0064]).

Accordingly, the amendments to claim 1 of the main request comply with Article 123(2) EPC.

*2.2 Clarity*

In the decision under appeal, the expression "*wherein the thicknesses of the individual layers are within the characteristic diffusion length of the exciton*" was considered to lack clarity in the sense of Article 84 EPC. In particular, there was no unambiguously clear defined method established of measuring the diffusion length of the exciton. The vagueness of this parameter was exemplified by the prior art data provided in the application, where for the well-known material CuPc, one reported literature value was 100 Å and a second literature reported a value of 680 Å (cf application, paragraph [0064], table).

The appellant argued that the expression was clear, as the different values reported were not due to any uncertainty in determining the exciton diffusion length, but rather were a result of the materials being different in terms of purity, morphology and processing.

In the board's judgement, although it cannot be ruled out that the different values reported in literature for the exciton diffusion length for a given material, besides possibly being the result of the materials being different, may be caused by measurement errors

and thus possibly depend on the measurement method used, the parameter as such is considered to be clear in the present case within the context in which it is used in the application.

The exciton diffusion length is neither an unusual parameter, nor a parameter defined by the method used to measure it, which would require the method to be specified. In fact, the exciton diffusion length is widely referred to in the literature and commonly correlated to the thickness of the photoconversion layer for optimising the conversion efficiency (cf eg document D8). Moreover, for a given photoconversion layer with given material properties it will be possible for a person skilled in the art to establish whether the layer thickness is within the characteristic diffusion length of the exciton generated within that layer.

Accordingly, claim 1 is considered to be clear and, thus, meets the requirements of Article 84 EPC 1973.

*2.3 Novelty*

Document D2 discloses a photovoltaic cell fabricated as a flexible fibre.

In particular, D2 discloses a photosensitive device structure (300a), comprising:
a conductive core (302, 304) including a first electrode (304);
an organic layer (310),
wherein the organic layer (310) surrounds the core and is electrically connected to the first electrode; and
a transparent second electrode (306) surrounding and electrically connected to the organic layer (310) (cf

page 9, lines 1 to 15; page 10, line 8 to page 15, line 7; figure 3A).

According to D2, "*In various illustrative embodiments, the photoconversion materials 110 and 310 include a heterojunction composite material. Suitable heterojunction composite materials include fullerenes (e.g., $C_{60}$), fullerene particles, or carbon nanotubes. The heterojunction composite material may be dispersed in polythiophene or some other hole transport material*" (cf page 12, lines 17 to 20).

Although most of the remaining parts of D2 relate to dye-sensitized solar cells (DSSC) typically comprising a nanomatrix material and a dye forming the photoconversion layer, the embodiments above rather relate to the broader class of dispersed heterojunction photovoltaic cells with photoconversion based on the generation of excitons diffusing to the interface where they split.

Not disclosed in D2 is, however, the provision of a juxtaposition of an acceptor layer and a donor layer and wherein the thicknesses of the individual layers are within the characteristic diffusion length of the exciton.

Accordingly, the subject-matter of claim 1 of the main request is new over document D2, Article 54(1) EPC 1973.

The subject-matter of claim 1 is also new over the remaining available, more remote prior art.

*2.4 Inventive step*

As discussed above, having regard to document D2, which is considered to provide the closest prior art, the subject-matter of claim 1 of the main request differs in that a two-layer photoconversion layer is used, with specific thicknesses for each of the two layers.

Accordingly, the objective problem to be solved relative to document D2 may be formulated as finding suitable alternative materials for the photoconversion layer.

The setting of the above problem is considered to be obvious to a person skilled in the art. Indeed, contrary to what is argued by the appellant, document D2 is not exclusively directed at DSSC devices, but rather would be considered by a skilled person as being primarily directed at a solar cell in the form of a fibre. The use of a dye-sensitized photoconversion material is extensively discussed but not as the only viable option, the use of fullerenes dispersed in polythiophene or some other hole transport material being a further possibility. Hence, the choice of the photoconversion material used is only of secondary importance.

In an attempt to solve the above problem posed and to find suitable alternative photoconversion materials, the skilled person would consider document D8 which is concerned with organic thin film photovoltaic devices based on fullerenes ($C_{60}$) and a low molecular-weight material (CuPc) for efficient photon-to-current conversion (cf chapter "*Introduction*").

In particular, D8 proposes a two-layer photoconversion structure with a donor layer of Cu-phthalocyanine (CuPc) and an acceptor layer of Buckminsterfullerene

($C_{60}$) (cf figure 1(a)). Document D8 determines the optimum layer thickness as a function of both the exciton diffusion length L and the absorption coefficient of the absorbing material α. The optimum thickness is when the donor-acceptor interface lies at the position of the maximum exciton density, yielding the maximum photocurrent (cf page 3638, left-hand column, last paragraph to page 3639, left-hand column, first paragraph; figure 8).

According to D8 the optimum layer thickness for the CuPc layer is 58 nm whereas the exciton diffusion length is 68 nm. Accordingly, in D8 the thickness of the donor layer is within the characteristic diffusion length of the exciton as per claim 1 (cf D8, page 3637, right-hand column, first paragraph; figure 8).

For the $C_{60}$ layer, according to D8 the optimum layer thickness is in the range of 40 to 60 nm (cf page 3637, left-hand column, second paragraph; figure 5).

According to the appellant, the exciton diffusion length for $C_{60}$ was 40 nm and therefore the layer thickness of the $C_{60}$ acceptor layer of D8 was not within the characteristic diffusion length of the exciton as required by claim 1.

It is, however noted that it is questionable whether a thickness of 40 to 60 nm is not within the exciton diffusion length for $C_{60}$ in D8, as the exciton diffusion length of 40 nm provided by the appellant on the one hand corresponds to the lower thickness recommended in D8 and on the other hand apparently stems from the table provided in the application and thus need not be applicable to the actual layer of D8.

At any rate, it is noted that the determination in document D8 of an optimum layer thickness is based on a consideration both of the exciton diffusion length and the light absorption in the layer. As is readily apparent from D8, for materials with shorter exciton diffusion lengths (see eg PVV in figure 8), the optimum layer thickness is greater than exciton diffusion length in order to achieve a reasonable absorption within the layer and thus a reasonable generation of excitons. Indeed, as is well known to a person skilled in the art in this respect, competing requirements must be balanced. One calls for small layer thicknesses within the exciton diffusion length in order to prevent recombination of the exciton before it reaches the interface and dissociates to contribute to the photocurrent. The other calls for large layer thicknesses in order to absorb most of the incident radiation and to produce a large number of excitons.

It would, however, be readily apparent to the skilled person that based on a less sophisticated consideration, not taking account of absorption in the respective layers, the optimum layer thickness is only determined by the diffusion length of the exciton. Based hereon, it would be obvious to the skilled person to provide the thicknesses of the individual layers within the characteristic diffusion length of the exciton.

It is also acknowledged in the application that the exciton diffusion length and the absorption of the material provide competing requirements inherently requiring trade-offs to be made in selecting the thickness of the organic layers (cf description, paragraph [0058] and [0059]). Hence, it follows that relating the thicknesses of the individual layers only

to the characteristic diffusion length of the exciton is merely a simplification and does not produce any unexpected effect.

Claim 1 is, according to the appellant, in this respect based on the description, according to which "*The individual layers may preferably be sufficiently thick for efficient absorption of light, while being within the characteristic diffusion length of the excitons*" (cf paragraph [0064]). While formally providing a basis for relating the thicknesses of the individual layers only to the characteristic diffusion length of the exciton, clearly this is a mere simplification without any further merit.

Accordingly, the subject-matter of claim 1 according to the main request is, having regard to the state of the art, obvious to a person skilled in the art and, thus, lacks an inventive step in the sense of Article 56 EPC 1973.

2.5 The appellant's main request is, therefore, not allowable.

*3. First auxiliary request*

*3.1 Amendments*

Claim 1 of the first auxiliary request, with respect to claim 1 of the main request, includes the following additional feature:

"*wherein the thickness of the first electrode (204) is greater than or equal to*

$$\frac{\rho_1 . L^2 . \Phi . \eta_{pwr}}{0.05 . FF^2 . V_{oc}^2}$$

*where $\rho_1$ is the resistivity of the first electrode, L is uninterrupted length of the photosensitive device structure, $\Phi$ is optical flux, $\eta_{pwr}$ is the device's power efficiency, FF is the fill factor, and $V_{oc}$ is open circuit voltage*"

This additional feature is based on the description as originally filed (cf paragraph [0081]).

Accordingly, the amendments to claim 1 of the first auxiliary request comply with Article 123(2) EPC.

*3.2 Inventive step*

The above additional feature in claim 1 provides a practical minimum thickness for the first, inner electrode of the device, where the inner electrode consists of a coating of conductive material on an insulating fibre core. In particular, by selecting an acceptable voltage drop along the length of the fibre when exposed to light and connected to a load, ohmic losses within the device are kept within reasonable limits.

As the technical effect achieved by the above additional feature of claim 1 is unrelated to that achieved by the distinguishing feature over D2 discussed above for the main request, which is an optimisation of the efficiency of the photoconversion layers, an assessment on the basis of partial problems is appropriate.

Having regard to the above additional feature concerning the thickness of the first electrode, the objective, partial problem to be solved relative to D2 may, thus, be formulated as to determine a suitable thickness.

As is apparent from the corresponding disclosure in the description, the expression for the thickness of the first electrode claimed is based on the assessment that a 5% voltage drop along the length of the fibre during operation is allowed. This assessment is based on practical considerations, which are considered to fall within the competence of an average practitioner. Clearly, a higher voltage drop would lead to higher ohmic losses in the device, reducing the power output and thus the usefulness of the device. A lower voltage drop would require a thicker electrode.

The expression claimed follows from straightforward physical and geometrical considerations. As can be seen from the description, the claimed expression is derived from standard expressions for optical power, efficiency, fill factor, resistivity and the cross-sectional area of the electrode (cf paragraph [0081]).

The appellant argued that in deriving the claimed expression, non-obvious assumptions were made at various steps, so that the expression involved an inventive step. In particular, it was argued that in the equation (2) for the optical power

$P_{opt} \geq \Phi.d.L$

it was not obvious to take the diameter of the first electrode d.

The board does not agree. The reason why the diameter of the first electrode d is taken in the application, is that the thickness of the photoactive layers (about 100 nm) is negligeable compared to the diameter of the first electrode (comparable to that of the overall fibre, ie about 10-100 µm)(cf paragraph [0080]. The equation above thus provides a fair approximation.

Since in the fibre of D2, when combined with D8, similarly, the thickness of the photoactive layers (about 100 nm) is minimal compared to the diameter of the first electrode (comparable to that of the fibre core, eg between 75 and 1000 µm (cf D2, page 10, lines 16 to 25)), the above approximation would be obvious to a skilled person.

The appellant moreover argued that the expression for the cross-sectional area of the first electrode

$A_{cs} \approx \pi.d.t$

was based on further non-obvious assumptions.

Again, the board does not agree. The expression provides a straightforward approximation of the cross-sectional area for the case the thickness of the electrode t (ie the thickness of the coating) is substantially smaller than the diameter of the electrode d (corresponding essentially to the diameter of the fibre core), which typically is the case. Indeed, in D2 the thickness of the inner electrode (eg about 0.5 to 1 µm (cf D2, page 11, lines 11 to 18)) is substantially smaller than its diameter. Also this approximation would, thus, be obvious to a skilled person.

The claimed equation for the electrode thickness (equation (6)) follows in a straightforward manner from combining equations (2) to (5) and the above expression for the cross-sectional area of the electrode.

Moreover, it is noted that the expression provides a lower limit for the electrode thickness. The board holds that it would always be obvious to choose a thick inner electrode, ie one that is thicker than the given lower limit, providing lower losses.

Accordingly, also the subject-matter of claim 1 according to the first auxiliary request is, having regard to the state of the art, obvious to a person skilled in the art and, thus, lacks an inventive step in the sense of Article 56 EPC 1973.

3.3 The appellant's first auxiliary request is, thus, not allowable either.

*4. Second auxiliary request*

*4.1 Amendments*

Claim 1 of the second auxiliary request, with respect to claim 1 of the first auxiliary request, includes the additional feature that the heterojunction in the device structure is a bulk heterojunction.

This additional feature is based on the description as originally filed (cf paragraph [0068]).

Accordingly, the amendments to claim 1 of the second auxiliary request comply with Article 123(2) EPC.

*4.2 Inventive step*

According to the application, the bulk heterojunction may be an interpenetrating network of donor and acceptor materials. Unlike a substantially flat heterojunction, the absorption of a photon may occur near the donor-acceptor interface, increasing the probability of charge dissociation (cf paragraph [0068]).

Accordingly, having regard to this further distinguishing feature the problem to be solved may generally be defined as to improve the efficiency of the device.

As indicated in the application, the use of bulk heterojunctions for improving efficiency is well known (cf paragraphs [0067] to [0069]). In particular, according to document D10, cited in this respect as prior art in the application, a problem with bilayer planar junction cells with a total thickness of the order of the optical absorption length is that, since the exciton diffusion length is typically an order of magnitude smaller than the optical absorption length, a large fraction of the photogenerated excitons remains unused for photocurrent generation, limiting the power conversion efficiency.

In document D10, this problem is solved through the introduction of a bulk heterojunction. According to D10, in a bulk heterojunction, the donor-acceptor interface is highly folded such that photogenerated excitons find an interface within the exciton diffusion length of their generation site.

Accordingly, it would be obvious for a person skilled in the art, in order to improve the efficiency of the device, to provide a bulk heterojunction as suggested in D10.

The appellant argued that D10 in fact led away from the claimed invention as the bulk heterojunction as presented in D10 made it unnecessary to put any restriction on the thickness of the donor and acceptor layers as required by claim 1.

In the board judgement, however, it is clear from D10 that even for a bulk heterojunction, still the thicknesses of the donor and acceptor layers must be such that photogenerated excitons find an interface within the exciton diffusion length of their generation site.

Accordingly, also the subject-matter of claim 1 according to the second auxiliary request is, having regard to the state of the art, obvious to a person skilled in the art and, thus, lacks an inventive step in the sense of Article 56 EPC 1973.

4.3 Therefore, the appellant's second auxiliary request is not allowable either.

**Order**

**For these reasons it is decided that:**

The appeal is dismissed.

The Registrar: The Chairman:

S. Sánchez Chiquero G. Eliasson

Decision electronically authenticated