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(72) Inventors:  
 • **Wojciechowski, Krzysztof Tomasz**  
**32-082 Wieckowice (PL)**  
 • **Marszalek, Konstanty**  
**31-358 Krakow (PL)**

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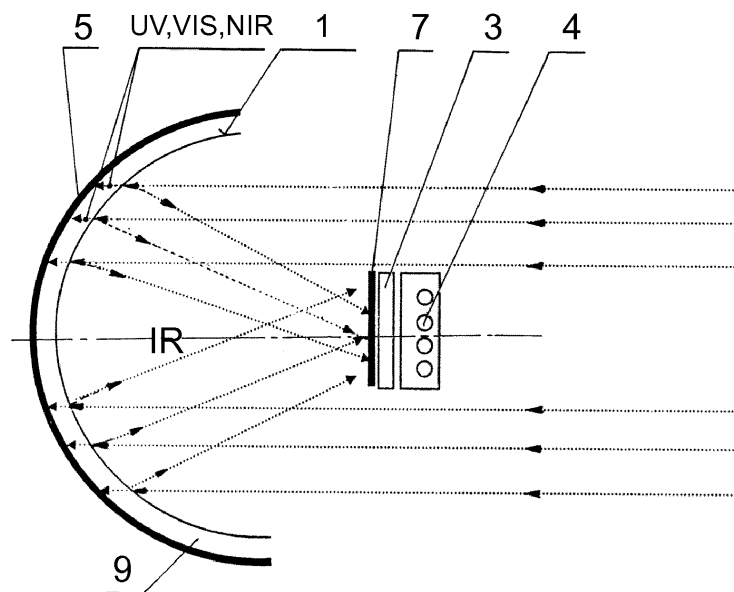
(74) Representative: **Pawlowski, Adam**  
**Eupatent.PL**  
**ul. Zeligowskiego 3/5**  
**90-752 Lodz (PL)**

(71) Applicant: **Akademia Gorniczo-Hutnicza im. Stanisława Staszica w Krakowie**  
**30-059 Krakow (PL)**

(54) **A hybrid solar energy converter**

(57) A hybrid converter of solar energy, the converter comprising: a selective concave mirror (1) configured to focus solar radiation; a thermoelectric module (3) located at a focus point of the concave mirror (1); a radiator (4) for cooling the working liquid flow adjacent to a cold surface of the thermoelectric module (3); and a set of photovoltaic cells (5) located behind the concave mirror (1) with respect to the sun; the converter being characterized

in that the selective concave mirror (1) is reflective for infrared (IR) radiation of electromagnetic waves of wavelength greater than  $1,1 \mu\text{m}$  and is transparent to ultraviolet (UV), visible (VIS) and near-infrared (NIR) radiation of wavelength from  $0,72$  to  $1,1 \mu\text{m}$ ; and the photovoltaic cells (5) are located such that they cover the area of the projection of the whole surface of the concave mirror (1).



**Fig. 1**

## Description

### TECHNICAL FIELD

**[0001]** The present invention relates to conversion of solar energy to electric energy by a hybrid converter with photovoltaic cells and thermoelectric modules.

### BACKGROUND

**[0002]** Approximately half of the energy of full spectrum of solar radiation is comprised in ultraviolet (UV) and visible (VIS) frequencies, while the remaining part is comprised in near infrared (NIR) and mid-wavelength infrared (MWIR) frequencies. Photovoltaic cells, utilising photovoltaic effect, are one of the most efficient devices for converting solar energy into electric energy (electricity). The photovoltaic cells can be made of ceramic semiconductors, for example based on Si, Ge, Se or polymer materials.

**[0003]** The power efficiency of the most effective cells made of monocrystalline silicon exceeds 20%. One of the factors influencing the cell efficiency is a range of conversion of radiation, which for silicon cells is limited to the visible range (VIS, covering wavelengths ( $\lambda$ ) from 380 to 720 nm), ultraviolet (UV, covering wavelengths 300 to 380 nm) and near-infrared (NIR, covering wavelengths from 720 to 1100nm). Infrared (IR) radiation having wavelength above 1100 nm is not converted to electrical energy by a p-n semiconductor junction responsible for the photovoltaic effect, and causes only heating of the cell. This is disadvantageous, as it significantly decreases the photovoltaic cell efficiency.

**[0004]** The Polish patent PL 203881 discloses a photovoltaic cell integrated with a heat exchanger that receives the heat of the cell and transfers it to a working liquid.

**[0005]** Common thermoelectric modules are able to convert thermal energy into electrical energy with 5% efficiency when the temperature difference between the cold and the hot side of the module is about 200°C.

**[0006]** A hybrid solution, directly combining a photovoltaic cell with a thermoelectric module, could seemingly allow for a significant increase of efficiency. However, theoretical calculations and practical experiments have shown that such solution is prone to the above-mentioned negative effect of efficiency loss of photovoltaic cells related to temperature increase.

**[0007]** A US patent application US2012048322 discloses a hybrid solar converter which addresses the above-mentioned problem by structurally separating the photovoltaic cell from the thermoelectric module. It comprises a concave mirror for focusing solar radiation on a selective, reflecting-transmitting mirror located at its focus point. The mirror reflects UV and VIS radiation and is transparent to IR radiation. The IR radiation is incident on a thermoelectric module located behind the mirror. The cold side of the thermoelectric module is coupled

with a radiator for heating a working liquid. The UV and VIS radiation reflected from the mirror is directed through a hole in the mirror towards a photovoltaic cell. The total electric power of the converter is approximately a sum of the power of the photovoltaic cell and the thermoelectric module. The overall energy efficiency is increased by collection of the heat by the radiator of the thermoelectric module. However, the electrical energy generated in the photovoltaic cell is significantly reduced by the fact that the reflected UV and VIS radiation is focused in the axis of the concave mirror. This narrows the area of solar energy transformation and focuses the energy on a small area.

### 15 SUMMARY

**[0008]** There is presented a hybrid converter of solar energy, the converter comprising: a selective concave mirror configured to focus solar radiation; a thermoelectric module located at a focus point of the concave mirror; a radiator for cooling the working liquid flow adjacent to a cold surface of the thermoelectric module; and a set of photovoltaic cells located behind the concave mirror with respect to the sun. The selective concave mirror is reflective for infrared (IR) radiation of electromagnetic waves of wavelength greater than 1,1  $\mu\text{m}$  and is transparent to ultraviolet (UV), visible (VIS) and near-infrared (NIR) radiation of wavelength from 0,72 to 1,1  $\mu\text{m}$ ; and the photovoltaic cells are located such that they cover the area of the projection of the whole surface of the concave mirror.

**[0009]** Preferably, the concave mirror is made of transparent glass covered with a transparent semiconductor coating made of metals and/or metal oxides, preferably indium-tin oxides ITO.

**[0010]** Preferably, the concave mirror has a parabolic or semi-cylindrical or cylindrically-parabolic shape.

**[0011]** Preferably, the concave mirror is made of a semiconductor coating applied on the inner, transparent surface of a glass pipe, in the range of a central angle smaller than 90°, wherein the bisector of the concave mirror is directed at the thermoelectric module, mounted in a geometric axis of the pipe, and wherein the thermoelectric module has its hot surface coated with an infrared absorber and its cold surface connected with the radiator

**[0012]** Preferably, the converter comprises a silicon photovoltaic cell located behind the concave mirror and distanced from the concave mirror by an air-gap.

**[0013]** Preferably, the external surface of the pipe, in the range of the central angle of the concave mirror, is coated with a thin layer photovoltaic cell, preferably made of CdTe or a:Si.

**[0014]** Preferably, only a section of the surface of the mirror is covered with photovoltaic cells.

**[0015]** Preferably, the whole surface of the mirror is covered with photovoltaic cells.

## BRIEF DESCRIPTION OF FIGURES

[0016] The present invention is shown by means of exemplary embodiments on a drawing, in which:

Fig. 1 shows a schematic diagram of the converter,  
Fig. 2 shows an example embodiment utilizing a glass pipe

Fig. 3 shows a section of a surface panel comprising pipe converters of Fig. 2.

## DETAILED DESCRIPTION

[0017] The solar converter comprises a selective concave mirror 1 configured to focus solar radiation and being reflective to IR radiation (wavelengths greater than 1,1  $\mu\text{m}$ ) and transparent to UV and VIS (and preferably NIR) radiation (wavelengths from 0,72 to 1,1  $\mu\text{m}$ ). The selective concave mirror 1 may be formed as two separate elements, as a layered element (as explained in the embodiment of Fig. 2) or as a single uniform element. A set of photovoltaic cells 5 is located behind (with respect to the sun) the concave mirror 1, on its whole projecting surface. In other words, photovoltaic cells 5 are located behind the concave mirror 1 with respect to the focus point of the mirror 1. A thermoelectric module 3 is located at the focus point of the concave mirror 1. The hot surface of the thermoelectric module 3 is coated with a layer of an infrared absorber 7. A radiator 4, coupled with a working liquid flow, is coupled with the cold surface of the thermoelectric module 3.

[0018] As shown in the embodiment of Fig. 2, the selective concave mirror 1 can be formed by a section 6A (marked by a bold line) of a transparent glass pipe 6, the section 6A having the central angle  $\omega$  of the inner surface smaller than  $90^\circ$ , and having the inner surface coated by indium tin oxide (ITO) layer 6B. In other embodiments, other coating metal and/or metal oxide layers 6B may be used. The thermoelectric module 3 is located on the bisector of the central angle  $\omega$ , in the geometrical axis of the pipe 6. The hot surface of the module 3 is coated with an infrared absorber layer 7. The cold surface of the module 3 is connected with the radiator 4 coupled with a working liquid flow or an air radiator.

[0019] The photovoltaic cell 5, preferably made of monocrystalline silicon, is located outside the pipe 6 at a distance of an air-gap 9, which may be 2 mm, in the range of projection of the central angle  $\omega$  of the concave mirror 1. The photovoltaic cell may be of a thin-layer type, made for example from CdTe, formed as a coating on the external surface of the pipe 6 in the range of the central angle  $\omega$ . In another embodiment, a silicon photovoltaic cell may be applied on the external surface of the pipe 6 within the range of the central angle  $\omega$  as a thin layer, made for example from CdTe or a:Si.

[0020] In other embodiments, the concave mirror 1 may have a parabolic or cylindrically-parabolic shape.

[0021] Fig. 3 presents a panel comprising a plurality of

pipes 6 arranged in parallel within a frame. The pipes 6 comprise photovoltaic cells 5 and thermoelectric modules 3. The radiators of the thermoelectric modules 3 are connected to collectors 8 of the working liquid flow, for example collectors of a water heater.

[0022] The efficiency of conversion of electromagnetic radiation energy depends on the angle of incidence of the waves. It may depend on the day period (morning, noon, evening), on the season (winter, summer) as well as the latitude (equator countries, near-poles countries). Therefore, the semiconductor surface or the glass panels may be structured such as to decrease this angular dependency of efficiency.

[0023] In another embodiment, only a fragment of the mirror 1 surface is covered with photovoltaic cells 5.

[0024] In the converter presented herein, the energy is converted first in the photovoltaic modules, which are located on a large area and receive UV, VIS and NIR radiation, which penetrates via the whole surface of the concave mirror. The applied sequence of conversion of solar radiation with a use of high-efficiency photovoltaic and thermoelectric materials allows achieving increase of efficiency of solar energy conversion into electrical energy.

## Claims

1. A hybrid converter of solar energy, the converter comprising:

- a selective concave mirror (1) configured to focus solar radiation;
- a thermoelectric module (3) located at a focus point of the concave mirror (1);
- a radiator (4) for cooling the working liquid flow adjacent to a cold surface of the thermoelectric module (3); and
- a set of photovoltaic cells (5) located behind the concave mirror (1) with respect to the sun;

the converter being **characterized in that**

- the selective concave mirror (1) is reflective for infrared (IR) radiation of electromagnetic waves of wavelength greater than 1,1  $\mu\text{m}$  and is transparent to ultraviolet (UV), visible (VIS) and near-infrared (NIR) radiation of wavelength from 0,72 to 1,1  $\mu\text{m}$ ; and
- the photovoltaic cells (5) are located such that they cover the area of the projection of the whole surface of the concave mirror (1).

2. The converter according to claim 1, **characterized in that** the concave mirror (1) is made of transparent glass covered with a transparent semiconductor coating made of metals and/or metal oxides, preferably indium-tin oxides ITO.

3. The converter according to claim 1 **characterized in that** the concave mirror (1) has a parabolic or semi-cylindrical or cylindrically-parabolic shape.
4. The converter according to claim 2 or 3 **characterized in that** the concave mirror (1) is made of a semiconductor coating (6B) applied on the inner, transparent surface (6A) of a glass pipe (6), in the range of a central angle ( $\omega$ ) smaller than  $90^\circ$ , wherein the bisector of the concave mirror (1) is directed at the thermoelectric module (3), mounted in a geometric axis of the pipe (6), and wherein the thermoelectric module (3) has its hot surface coated with an infrared absorber (7) and its cold surface connected with the radiator (4)
5. The converter according to claim 4 **characterized in that** it comprises a silicon photovoltaic cell (5) located behind the concave mirror (1) and distanced from the concave mirror (1) by an air-gap (9).
6. The converter according to claim 4 **characterized in that** the external surface of the pipe (6), in the range of the central angle ( $\omega$ ) of the concave mirror (1), is coated with a thin layer photovoltaic cell (5), preferably made of CdTe or a:Si.
7. The converter according to claim 6 **characterized in that** only a section of the surface of the mirror (1) is covered with photovoltaic cells (5).
8. The converter according to claim 6 **characterized in that** the whole surface of the mirror (1) is covered with photovoltaic cells (5).

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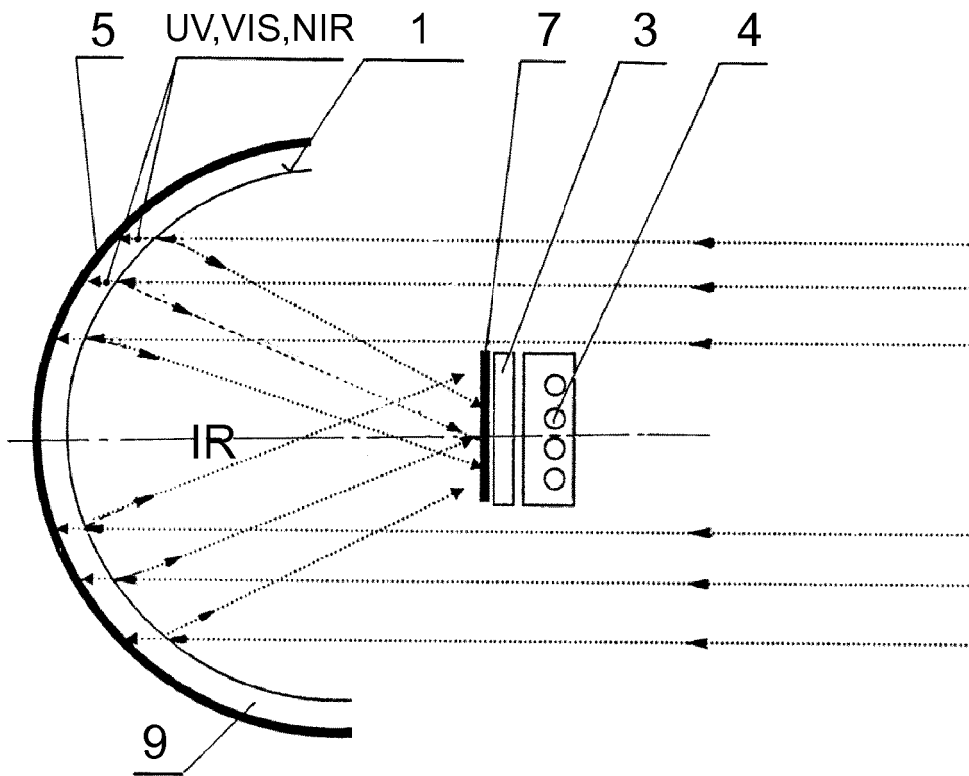


Fig. 1

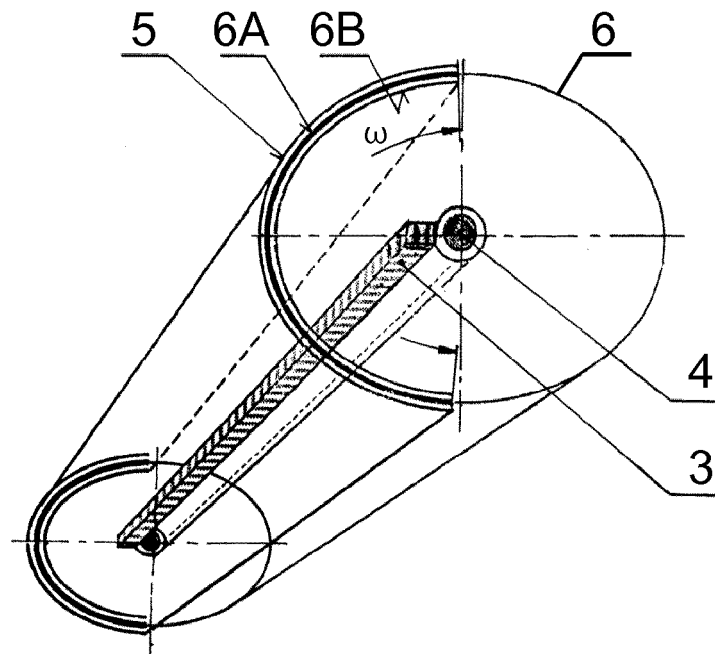
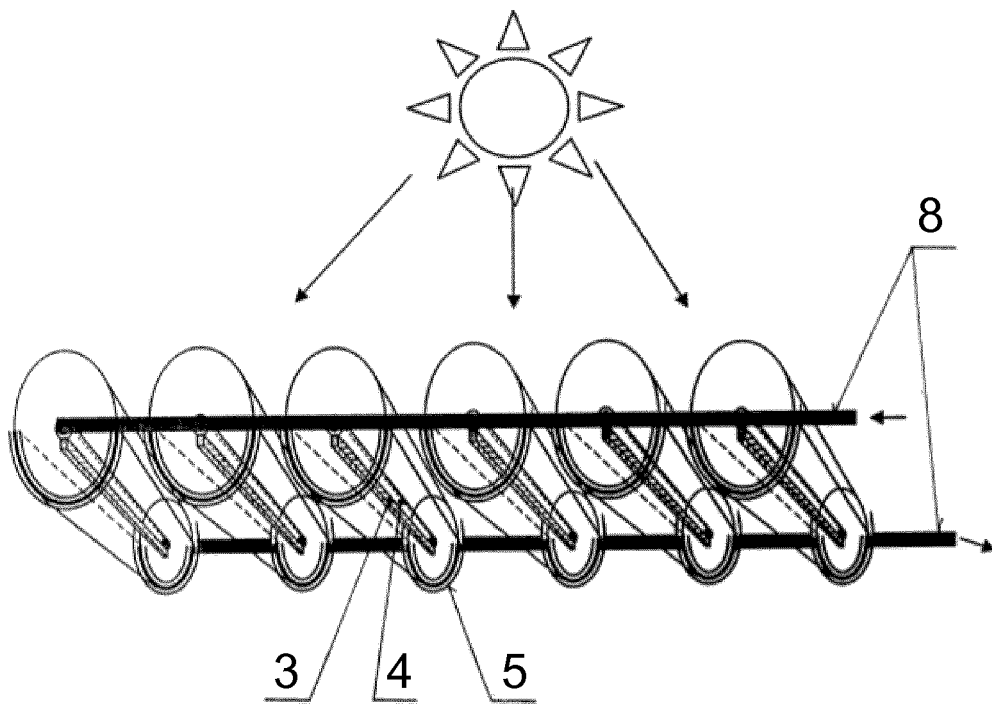


Fig. 2



**Fig. 3**



EUROPEAN SEARCH REPORT

Application Number  
EP 14 17 7181

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| DOCUMENTS CONSIDERED TO BE RELEVANT                                                                                                                                                                                                                    |                                                                                                                                                       |                                                                                                                                                                                                                                                                                       |                                         |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------|
| Category                                                                                                                                                                                                                                               | Citation of document with indication, where appropriate, of relevant passages                                                                         | Relevant to claim                                                                                                                                                                                                                                                                     | CLASSIFICATION OF THE APPLICATION (IPC) |
| X                                                                                                                                                                                                                                                      | DE 10 2005 054364 A1 (DURLUM LEUCHTEN [DE]) 16 May 2007 (2007-05-16)                                                                                  | 1,3,4                                                                                                                                                                                                                                                                                 | INV.<br>H01L31/052<br>H02S10/10         |
| Y                                                                                                                                                                                                                                                      | * paragraph [0011] *                                                                                                                                  | 2                                                                                                                                                                                                                                                                                     |                                         |
| A                                                                                                                                                                                                                                                      | * paragraph [0009] *                                                                                                                                  | 5-8                                                                                                                                                                                                                                                                                   |                                         |
|                                                                                                                                                                                                                                                        | * paragraph [0003] *                                                                                                                                  |                                                                                                                                                                                                                                                                                       |                                         |
|                                                                                                                                                                                                                                                        | -----                                                                                                                                                 |                                                                                                                                                                                                                                                                                       |                                         |
| A                                                                                                                                                                                                                                                      | WO 2008/146287 A2 (AEROSUN TECHNOLOGIES AG [CH]; SHIFMAN ELI [IL]) 4 December 2008 (2008-12-04) * page 6; figure 1 *                                  | 1-8                                                                                                                                                                                                                                                                                   |                                         |
|                                                                                                                                                                                                                                                        | -----                                                                                                                                                 |                                                                                                                                                                                                                                                                                       |                                         |
| A                                                                                                                                                                                                                                                      | WO 2010/147638 A2 (SHEETAK INC [US]; GHOSHAL UTTAM [US]; GUHA AYAN [US]) 23 December 2010 (2010-12-23) * page 4, line 8 - page 7, line 7; figure 1 *  | 1-8                                                                                                                                                                                                                                                                                   |                                         |
|                                                                                                                                                                                                                                                        | -----                                                                                                                                                 |                                                                                                                                                                                                                                                                                       |                                         |
| A                                                                                                                                                                                                                                                      | WO 2009/144700 A1 (RDC RAFAEL DEV CORP LTD [IL]; IDAN GAVRIEL J [IL]) 3 December 2009 (2009-12-03) * page 12, line 19 - page 14, line 21; figure 1a * | 1-8                                                                                                                                                                                                                                                                                   | TECHNICAL FIELDS SEARCHED (IPC)         |
|                                                                                                                                                                                                                                                        | -----                                                                                                                                                 |                                                                                                                                                                                                                                                                                       | H01L                                    |
| Y                                                                                                                                                                                                                                                      | WO 2010/136788 A1 (PILKINGTON GROUP LTD [GB]; CLARKE GREGORY CHARLES BERNARD [GB]; UNQUER) 2 December 2010 (2010-12-02) * the whole document *        | 2                                                                                                                                                                                                                                                                                     |                                         |
|                                                                                                                                                                                                                                                        | -----                                                                                                                                                 |                                                                                                                                                                                                                                                                                       |                                         |
| A                                                                                                                                                                                                                                                      | WO 2012/151215 A2 (BOSTWICK PAUL ALAN [US]) 8 November 2012 (2012-11-08) * figure 3 * * paragraph [0048] - paragraph [0056] *                         | 1-8                                                                                                                                                                                                                                                                                   |                                         |
|                                                                                                                                                                                                                                                        | -----                                                                                                                                                 |                                                                                                                                                                                                                                                                                       |                                         |
| A                                                                                                                                                                                                                                                      | EP 0 785 400 A1 (IZUMI HISAO [JP]) 23 July 1997 (1997-07-23) * column 3, line 6 - column 4, line 35; figure 1 *                                       | 1-8                                                                                                                                                                                                                                                                                   |                                         |
|                                                                                                                                                                                                                                                        | -----                                                                                                                                                 |                                                                                                                                                                                                                                                                                       |                                         |
| The present search report has been drawn up for all claims                                                                                                                                                                                             |                                                                                                                                                       |                                                                                                                                                                                                                                                                                       |                                         |
| Place of search<br>Berlin                                                                                                                                                                                                                              |                                                                                                                                                       | Date of completion of the search<br>10 November 2014                                                                                                                                                                                                                                  | Examiner<br>Chao, Oscar                 |
| CATEGORY OF CITED DOCUMENTS<br>X : particularly relevant if taken alone<br>Y : particularly relevant if combined with another document of the same category<br>A : technological background<br>O : non-written disclosure<br>P : intermediate document |                                                                                                                                                       | T : theory or principle underlying the invention<br>E : earlier patent document, but published on, or after the filing date<br>D : document cited in the application<br>L : document cited for other reasons<br>.....<br>& : member of the same patent family, corresponding document |                                         |

EPO FORM 1503 03 82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT  
ON EUROPEAN PATENT APPLICATION NO.

EP 14 17 7181

5

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

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| Patent document cited in search report | Publication date | Patent family member(s) | Publication date |
|----------------------------------------|------------------|-------------------------|------------------|
| DE 102005054364 A1                     | 16-05-2007       | DE 102005054364 A1      | 16-05-2007       |
|                                        |                  | DE 112006003764 A5      | 27-11-2008       |
|                                        |                  | EP 1949454 A1           | 30-07-2008       |
|                                        |                  | US 2008251124 A1        | 16-10-2008       |
|                                        |                  | WO 2007056984 A1        | 24-05-2007       |
| -----                                  |                  |                         |                  |
| WO 2008146287 A2                       | 04-12-2008       | NONE                    |                  |
| -----                                  |                  |                         |                  |
| WO 2010147638 A2                       | 23-12-2010       | US 2012048322 A1        | 01-03-2012       |
|                                        |                  | WO 2010147638 A2        | 23-12-2010       |
| -----                                  |                  |                         |                  |
| WO 2009144700 A1                       | 03-12-2009       | NONE                    |                  |
| -----                                  |                  |                         |                  |
| WO 2010136788 A1                       | 02-12-2010       | EP 2435379 A1           | 04-04-2012       |
|                                        |                  | WO 2010136788 A1        | 02-12-2010       |
| -----                                  |                  |                         |                  |
| WO 2012151215 A2                       | 08-11-2012       | AU 2012250840 A1        | 21-11-2013       |
|                                        |                  | CN 103620950 A          | 05-03-2014       |
|                                        |                  | EP 2705309 A2           | 12-03-2014       |
|                                        |                  | JP 2014517901 A         | 24-07-2014       |
|                                        |                  | SG 194750 A1            | 30-12-2013       |
|                                        |                  | US 2012279554 A1        | 08-11-2012       |
|                                        |                  | WO 2012151215 A2        | 08-11-2012       |
| -----                                  |                  |                         |                  |
| EP 0785400 A1                          | 23-07-1997       | AU 707630 B2            | 15-07-1999       |
|                                        |                  | AU 3578895 A            | 02-05-1996       |
|                                        |                  | BR 9509220 A            | 27-01-1998       |
|                                        |                  | CN 1160441 A            | 24-09-1997       |
|                                        |                  | EP 0785400 A1           | 23-07-1997       |
|                                        |                  | KR 100252687 B1         | 15-04-2000       |
|                                        |                  | US 6057504 A            | 02-05-2000       |
|                                        |                  | WO 9611364 A1           | 18-04-1996       |
| -----                                  |                  |                         |                  |

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82



**REFERENCES CITED IN THE DESCRIPTION**

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**Patent documents cited in the description**

- PL 203881 [0004]
- US 2012048322 A [0007]