



EUROPEAN PATENT APPLICATION

(43) Date of publication:
10.08.2022 Bulletin 2022/32

(51) International Patent Classification (IPC):
F28D 15/04^(2006.01) F28F 21/08^(2006.01)

(21) Application number: **22154190.7**

(52) Cooperative Patent Classification (CPC):
F28D 15/046; F28F 21/085

(22) Date of filing: **31.01.2022**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

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(30) Priority: **04.02.2021 US 202117167449**

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(54) **METAL WOODPILE CAPILLARY WICK**

(57) A heat pipe that employs a metal woodpile capillary wick. The heat pipe includes an outer enclosure defining a chamber therein that contains a working fluid, an evaporator section for converting the fluid to vapor in response to being heated from a heat source, and a condenser section for converting the vapor back into the fluid in response to cooling from a heat sink. The wick is positioned within the chamber in contact with the enclosure

and extends between the evaporator section and the condenser section. The wick includes a plurality of layers each having spaced apart parallel thermally conductive bars defining channels therebetween, where the bars in adjacent layers are oriented in different directions and where the condensed fluid flows through the channels in the wick from the condenser section to the evaporator section.

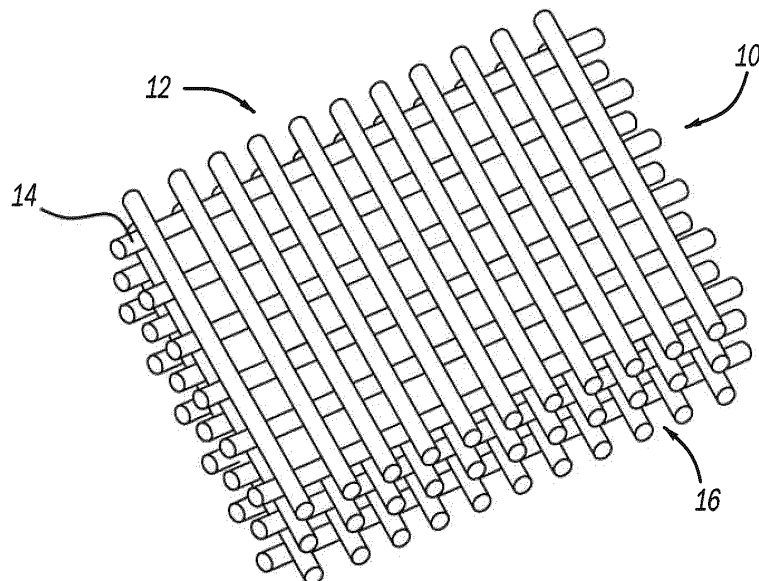


FIG - 1

Description

BACKGROUND

Field

[0001] This disclosure relates generally to a heat pipe and, more particularly, to a heat pipe employing a metal woodpile capillary wick.

Discussion of the Related Art

[0002] A heat pipe is a passive thermal device that uses an evaporating/condensing working fluid, such as water, to transport heat over long distances with lower thermal resistance than the best solid conductors, such as copper. A heat pipe is typically a sealed enclosure that is internally lined with a porous metal capillary wick that pulls the fluid via capillary pressure and has an open vapor cavity that carries the vapor phase of the fluid. An evaporator section is provided at one end of the heat pipe that is positioned adjacent to a heat source that heats the fluid and converts it to vapor by evaporation. The heated vapor is then pushed away from the evaporator section through the vapor cavity until it reaches a condenser section at an opposite end of the heat pipe that is positioned adjacent to a heat sink, where the vapor is condensed back to the fluid and releases heat. The condensed vapor is returned to the evaporator section by capillary action through the wick.

[0003] An ideal capillary wick for a heat pipe will have a high thermal conductivity to conduct heat into and out of the evaporator and condenser surface, a high permeability and capillary parameter to provide a high mass transport rate of the fluid, and a high specific surface area and vapor permeability to provide a high evaporation and condensation rate. Sintered copper is currently usually the go to material for heat pipe wicks. Sintered copper is a disordered porous material consisting of compacted copper microparticles that are sintered together to form a continuous solid network. Sintered copper has been optimized for heat pipe use for several decades. As such, heat pipe performance has largely saturated, as the wicking material cannot be further refined under the restrictive geometries available by sintered copper.

[0004] Sintered copper has a number of intrinsic problems for being an ideal wicking material for heat pipes. Specifically, sintered copper has a disordered morphology which forces both the fluid and the vented vapor through tortuous pathways that are full of constrictions and impingement surfaces. Thus, the fluid must travel through the complex open spaces surrounding the amorphous blob of sintered copper particles, which creates a large hydraulic resistance and a low capillary mass transport rate. These restrictions on mass transport are what ultimately create a "dryout" condition, which is the maximum heat flux that a heat pipe can sustain. By increasing the mass flow rate, an increase in the maximum thermal

load that can be carried by the heat pipe can be achieved.

[0005] Further, sintered copper particles are effectively "glued" together and are full of constrictions and interfaces that impede heat conduction. Heat is similarly forced to follow a tortuous pathway from the exterior surface and into the working fluid, which creates a large thermal resistance and a superheat at the heat source. The interfaces and tortuous pathway lead to a low effective thermal conductivity and reduce the rate that heat can be carried to where evaporation occurs.

[0006] Also, copper microparticles have feature sizes on the order of >10 microns. Since the surface-area-to-volume ratio of a porous medium scales roughly with $1/\text{length}$, this limits the total specific surface area that can be achieved by sintered copper. The large surface area of an evaporator or condenser leads to high rates of two-phase heat transfer. By moving to feature sizes that can be as small as tens of nanometers, the surface area (and rate of heat transfer) can increase by 2-3 orders of magnitude.

[0007] Further, the constraint on the geometry of the sintered copper also imposes limitations on the possible density and configuration of the porous medium. A packed bed of spheres in a random arrangement only gives 50-55% density with little room for tuning in one direction or the other. That means that a heat pipe cannot be optimized by the density as a free variable. Heat pipes that rely on sintered copper can only be locally optimized without being able to independently tune the amount of wicking material present or the arrangement of that material.

SUMMARY

[0008] The following discussion discloses and describes a heat pipe that employs a metal woodpile capillary wick. The heat pipe includes an outer enclosure defining a chamber therein that contains a working fluid, an evaporator section for converting the fluid to vapor in response to being heated from a heat source, and a condenser section for converting the vapor back into the fluid in response to cooling from a heat sink. The wick is positioned within the chamber in contact with the enclosure and extends between the evaporator section and the condenser section. The wick includes a plurality of layers each having spaced apart parallel thermally conductive bars defining channels therebetween, where the bars in adjacent layers are oriented in different directions and where the condensed fluid flows through the channels in the wick from the condenser section to the evaporator section.

[0009] Additional features of the disclosure will become apparent from the following description and appended claims, taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010]

Figure 1 is an isometric view of a metal woodpile capillary wick;

Figure 2 is a top view of the woodpile capillary wick shown in figure 1;

Figure 3 is a cross-sectional type side view of a heat pipe incorporating the woodpile capillary wick;

Figure 4 is an illustration of a metal woodpile capillary wick employing offset rectangular beams;

Figure 5 is an illustration of a metal woodpile capillary wick employing rectangular beams of different sizes; and

Figure 6 is an illustration of a metal woodpile capillary wick employing round and rectangular beams.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0011] The following discussion of the embodiments of the disclosure directed to a heat pipe employing a metal woodpile capillary wick is merely exemplary in nature, and is in no way intended to limit the disclosure or its applications or uses.

[0012] As will be discussed in detail below, this disclosure proposes a heat pipe employing a metal woodpile capillary wick. As used herein, a woodpile is a three-dimensional grid of aligned and orthogonal thermal conductor bars that are uniform in cross-section either rectangular or circular. By aligning the bars, the woodpile wick straightens both the heat conduction and fluid delivery pathways, which reduces both resistances. The straight fluid flow channels minimizes the hydraulic resistance and allows a direct line-of-sight for mass transport to occur. The cross-section shape, pitch and volume fraction of the bars can be independently tuned to provide maximum control of the precise material structure for optimizing the transport properties of the heat pipe. Fabrication techniques exist that can form the bars to have very small cross-sections, such as on the order of 100 nanometers.

[0013] Figure 1 is an isometric view and figure 2 is a top view of a metal woodpile capillary wick 10 of the type proposed above. The wick 10 includes a number of layers 12 of spaced apart parallel round conductor bars 14 defining flow channels 16 therebetween. The bars 14 are oriented so that they are orthogonal to each other from one layer 12 to an adjacent layer 12. The bars 14 can be made out of any suitable thermally conductive material, such as copper. The cross-sectional size, the cross-sectional shape, the pitch (spacing) and the orientation of the bars 14 can be selected for a particular application. Heat flows along the bars 14 in a straight direction and fluid flows through the channels 16 in a straight direction.

[0014] Figure 3 is a cross-sectional type side view of a heat pipe 20 including an outer conductive enclosure 22 defining an internal chamber 24 therein and having

end walls 26 and 28, where the enclosure 22 can have any suitable cross-sectional shape and be made of any suitable material for a particular application. The heat pipe 20 also includes an evaporator section 30 provided adjacent to the wall 26, where a heat source 32, such as an electronic device, is provided in thermal contact with the enclosure 22 in the section 30, and a condenser section 34 provided adjacent to the wall 28, where a heat sink 36, such as a metal block, is provided in thermal contact with the enclosure 22 in the section 34. A metal woodpile capillary wick 40 including conductor bars 42 configured in the manner discussed above is positioned within the chamber 24 in thermal contact with the enclosure 22. Heat from the heat source 32 is conducted into the wick 40 and the heat evaporates a working fluid, such as water, therein to vapor that is transported through a vapor cavity 44 in the chamber 24 outside of the wick 40 towards the condenser section 34. Heat is drawn out of the vapor in the condenser section 34 and is condensed back into the fluid and is wicked along the bars 42 in the wick 40 by the capillary action towards the evaporator section 30 to be reheated into vapor. Thus, the heat pipe 20 controls the temperature of the heat source 32. It is noted that although the wick 40 is only shown on one side of the enclosure 22, it can be provide all of the way around and in contact with the enclosure 22.

[0015] As mentioned above, the cross-sectional shape, pitch, volume fraction, etc. of the conductor bars 42 can be independently tuned for a particular heat pipe and its application. Each layer in the wick 40 can be configured differently than other layers to provide different characteristics so that it is not uniform, such as providing increased heat conduction near the enclosure 22 and increased evaporation near the vapor cavity 44.

[0016] Figure 4 is a side illustration of a metal woodpile capillary wick 50 having rectangular conductor bars 52 that have varying sizes and are offset from each other in layers 54 having the bars 52 going in the same direction. Figure 5 is a side illustration of a metal woodpile capillary wick 60 employing round conductor bars 62 going in one direction and rectangular conductor bars 64 going in an orthogonal direction in adjacent layers 66. Figure 6 is a side illustration of a metal woodpile capillary wick 70 employing rectangular conductor bars 72 of different sizes in adjacent layers 74. In all of these embodiments, the conductor bars in adjacent layers are orthogonal to each other. However, in other designs the bars in adjacent layers can be angled other than 90° relative to each other.

[0017] Any suitable fabrication technique can be used to fabricate a heat pipe including a metal woodpile capillary wick as described herein. For example, soft lithography or layer-by-layer templating and electroplating can be employed where the wick is built up layer-by-layer on a substrate and then the substrate is rolled to form the heat pipe.

[0018] The foregoing discussion discloses and describes merely exemplary embodiments of the present disclosure. One skilled in the art will readily recognize

from such discussion and from the accompanying drawings and claims that various changes, modifications and variations can be made therein without departing from the spirit and scope of the disclosure as defined in the following claims.

Claims

1. A heat pipe comprising:
 - an outer enclosure defining a chamber therein and containing a working fluid;
 - an evaporator section for evaporating the fluid to vapor in response to being heated from a heat source;
 - a condenser section for condensing the vapor back into the fluid in response to cooling from a heat sink; and
 - a capillary wick positioned within the chamber in contact with the enclosure and extending between the evaporator section and the condenser section, said wick including a plurality of layers each having spaced apart parallel thermally conductive bars defining channels therebetween where the bars in adjacent layers are oriented in different directions and where the condensed fluid flows through the wick from the condenser section to the evaporator section.
2. The heat pipe according to claim 1 wherein the bars in adjacent layers are orthogonal to each other.
3. The heat pipe according to claim 1 wherein the bars in every other layer are oriented in the same direction.
4. The heat pipe according to claim 3 wherein the bars that are oriented in the same direction in different layers are aligned with each other.
5. The heat pipe according to claim 3 wherein the bars that are oriented in the same direction in different layers are offset from each other.
6. The heat pipe according to claim 1 wherein some of the bars have a different cross-sectional size than other bars.
7. The heat pipe according to claim 1 wherein some of the bars have a different cross-sectional shape than other bars.
8. The heat pipe according to claim 1 wherein the bars are round in cross-section.
9. The heat pipe according to claim 1 wherein the bars are rectangular in cross-section.
10. The heat pipe according to claim 1 wherein the bars in some layers are round in cross-section and the bars in other layers are rectangular in cross-section.
11. The heat pipe according to claim 1 wherein the wick is designed to provide greater thermal capacity closer to the enclosure and greater evaporation farther from the enclosure.
12. The heat pipe according to claim 1 wherein the bars are copper bars.
13. A capillary wick comprising a plurality of layers each having spaced apart parallel thermally conductive bars defining channels therebetween where the bars in adjacent layers are oriented in different directions.
14. The capillary wick according to claim 13 wherein the bars in adjacent layers are orthogonal to each other.
15. The capillary wick according to claim 13 wherein the bars in every other layer are oriented in the same direction.

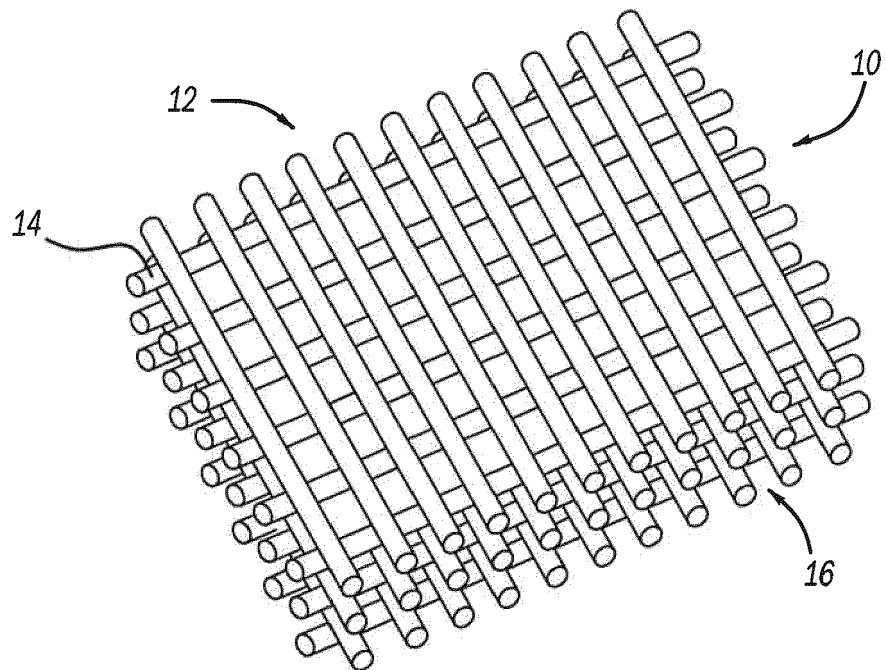


FIG - 1

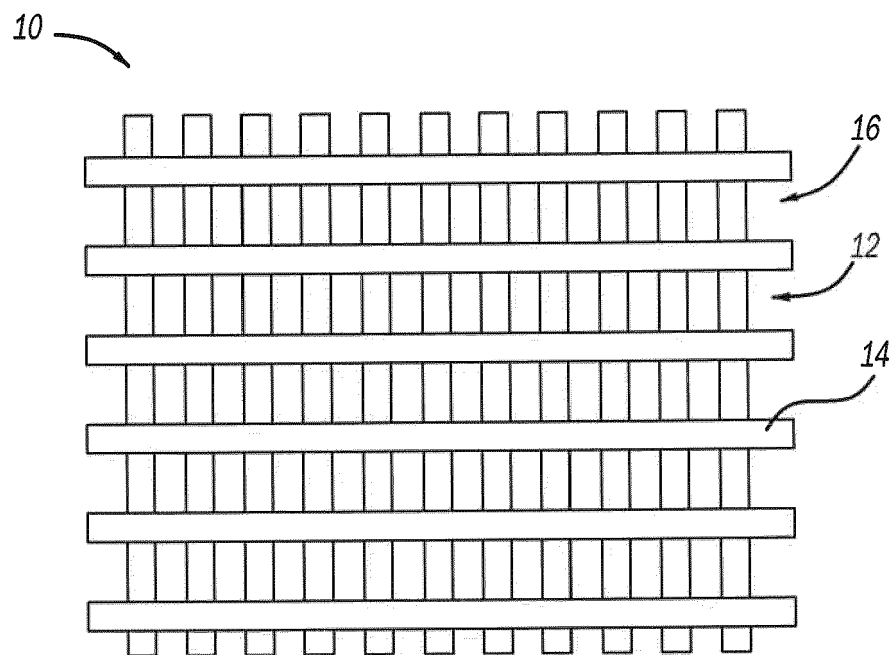
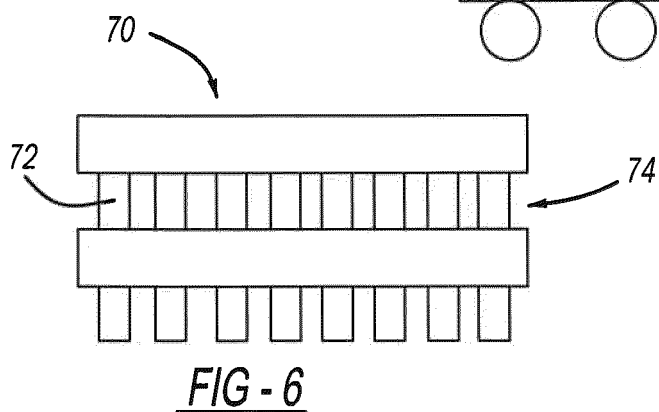
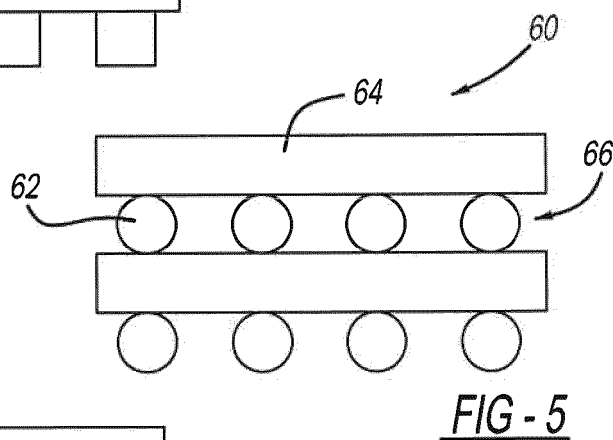
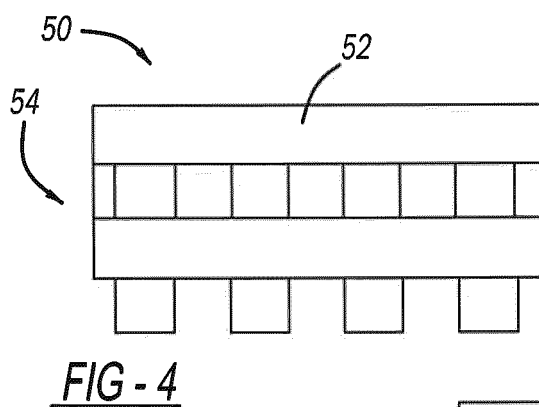
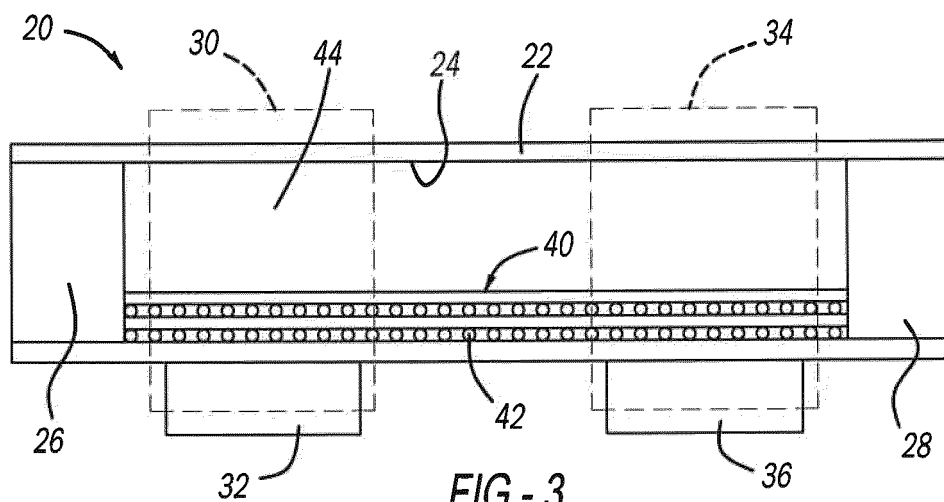


FIG - 2





EUROPEAN SEARCH REPORT

Application Number

EP 22 15 4190

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EPO FORM 1503 03.82 (P04C01)

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	US 2003/159809 A1 (VALENZUELA JAVIER A [US]) 28 August 2003 (2003-08-28) * figure 5A *	1-15	INV. F28D15/04 F28F21/08
A	WO 2005/060325 A1 (LS CABLE LTD [KR]; KIM HYUN-TAE [KR] ET AL.) 30 June 2005 (2005-06-30) * figures *	1-15	
A	US 2006/207751 A1 (HONG CHU-WAN [TW] ET AL) 21 September 2006 (2006-09-21) * figure 2 *	1-15	
A	US 2007/294892 A1 (YANG HSIUWEI [TW] ET AL) 27 December 2007 (2007-12-27) * figures *	1-15	
			TECHNICAL FIELDS SEARCHED (IPC)
			F28D F28F
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 30 May 2022	Examiner Mellado Ramirez, J
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

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

EP 22 15 4190

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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
US 2003159809 A1	28-08-2003	AU 2003217757 A1	09-09-2003
		CN 1639532 A	13-07-2005
		EP 1488182 A1	22-12-2004
		JP 4195392 B2	10-12-2008
		JP 2005518518 A	23-06-2005
		KR 20040088554 A	16-10-2004
		US 2003159809 A1	28-08-2003
		WO 03073032 A1	04-09-2003

WO 2005060325 A1	30-06-2005	CN 1895011 A	10-01-2007
		EP 1695601 A1	30-08-2006
		JP 2007519877 A	19-07-2007
		KR 20050060461 A	22-06-2005
		TW I266851 B	21-11-2006
		US 2007163755 A1	19-07-2007
		WO 2005060325 A1	30-06-2005

US 2006207751 A1	21-09-2006	TW I259895 B	11-08-2006
		US 2006207751 A1	21-09-2006

US 2007294892 A1	27-12-2007	TW 200800453 A	01-01-2008
		US 2007294892 A1	27-12-2007
