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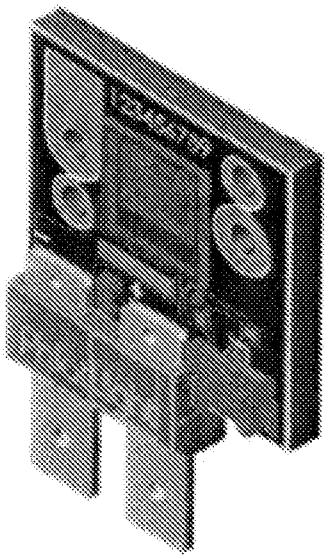
[Continued on next page]

(54) **Title:** FULL SPECTRUM LED ILLUMINATOR



(57) **Abstract:** An apparatus for providing a light output to an optical guide for illumination of an imaged object including a plurality of solid state light-emitting sources each of which are independently powered and independently controlled, each light-emitting source emitting light at a wavelength which is different from the wavelength emitted by the other light-emitting sources. The apparatus also includes a heat sink configured to thermally couple the plurality of solid state light-emitting sources and provide conduction of heat generated by the plurality of solid state light-emitting sources. The apparatus further includes an optical elements to collect, collimate, and combine the emissions from the plurality of solid state light-emitting sources into a combined beam of light to be optically coupled to the light guide.

FIG. 1

WO 2012/120380 A1

— *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))*

FULL SPECTRUM LED ILLUMINATOR

BACKGROUND OF THE INVENTION

[001] The present invention relates to an illumination system, in particular for endoscopy, and more particularly a full spectrum illumination system using light-emitting diodes (LED) and/or semiconductor lasers.

[002] Illumination systems for endoscopy, microscopy and similar optical imaging applications have for many years utilized arc lamp or halogen technology as the light source of choice. More recently, various forms of solid state light sources such as light emitting diodes or diode lasers have been introduced for use in some of these imaging applications. Due to the output brightness or output spectrum limitations of these solid state light sources, the use of LEDs and/or laser diodes has, until recently, been limited to optical imaging applications where low light levels are sufficient or where narrow spectrum illumination is required/desired.

[003] Achieving sufficiently bright, full visible spectrum illumination with solid state light sources has remained challenging for a number of reasons.

[004] a) Firstly, LED technology has been improving, but started far behind that of lamp technology in terms of total light output. Increasingly higher light outputs are now available, but light from a single phosphor-coated ("white") LED, for example, is still orders of magnitude below that of an arc lamp.

[005] b)Alternatively light from multiple, different colored (e.g. red, green and blue) LEDs can be combined using dichroic mirrors to "source" emitting over a wide spectral range. The imaging applications mentioned above, however, generally require coupling light into liquid, fiberoptic, or rod lens light guides.

Such optical light guides typically have both a small physical aperture with dimensions of a few mm across and a constrained/limited numerical aperture (NA). Moreover, etendue considerations rapidly constrain the practical implementation of such combined source illumination systems.

[006] c) Should the etendue considerations with a multiple different colored LED arrangement be overcome by a suitable arrangement of sources and dichroics with optical path lengths that are carefully equalized, then other implementation issues arise with respect to effective cooling and cost.

[007] Finally, although output brightness of red and blue LEDs has reached levels at which they can produce light with a brightness substantially equivalent to that of the red and blue portions of an arc lamp or a halogen lamp spectrum, the output of green LEDs tends to be substantially less than the green light produced by lamps.

[008] It would therefore be desirable and advantageous to address this problem and to obviate other prior art shortcomings by providing a cost-effective and reliable illuminator utilizing solid state light sources to produce a bright, color balanced, broad spectrum visible light output that may be effectively coupled to an optical light guide. It would also be desirable to include in such illuminator and in the resulting light emission, other light sources for UV or NIR illumination (e.g. for fluorescence excitation of tissue).

SUMMARY OF THE INVENTION

[009] According to one aspect of the present invention, an illuminator is disclosed which utilizes solid state light sources to produce a bright, color balanced, broad-spectrum, visible light output.

[0010]According to one advantageous feature of the invention, the illuminator may contain multiple high power LED light sources that span the visible spectrum (e.g. from 400 - 700 nm). These LED light sources are separately powered and controlled. The light produced by these LEDs is combined into a single beam using either mirrors or dichroic filters appropriately wavelength matched to the LED light output. The combined light may then be coupled into an optical light guide using an appropriate optical element such as a high (e.g. > 0.5) NA lens.

[0011] According to one advantageous feature of the invention, the illuminator may include LED light sources housed in discrete high thermal conductivity packages. The LED dies may be edge-emitting or surface emitting and they may be packaged in single or multi-die configurations.

[001 2] According to one advantageous feature of the invention, the illuminator may contain a combination of red, green and blue LED light sources. Alternatively or in addition, one or more of these LED light sources may have other hues of the visible spectrum, including violet, yellow, amber/orange LEDs, as required or desirable for the application (e.g. in the endoscope). Alternatively, or in addition, a single LED package may contain any combination of these color dies.

[001 3] According to one advantageous feature of the invention, to increase the green component of the emitted light and provide a more color balanced output, the illuminator may contain in addition to red and blue LED light sources at least two green LED light sources, such as a long wavelength green and a short wavelength green. The peak wavelengths and bandwidth of the two green LEDs is carefully selected to ensure that the combining optics produce maximum net green light output. In one embodiment the long wavelength green may have a peak wavelength at ~ 530 nm and an approximate FWHM bandwidth of +/- 40 nm and the short wavelength green may have a peak wavelength at ~515 nm and an approximate FWHM bandwidth of +/- 37 nm.

[0014] According to one advantageous feature of the invention, the LED light sources may be mounted on a heat sink in good thermal contact with a single heat spreader plate. The spreader plate may be a metal having high thermal conductivity, such as copper, aluminum, iron, diamond, gold or silver and the like. The spreader plate may be mounted on - or integral with - a passive cooling system, such as a finned heat sink or a heat pipe, or an active cooling system, such as a thermoelectric cooler (TEC) or liquid cooler. Thermal contact between the LEDs and the plate may be provided by, for example, soldering or with the application of a thermally conductive compound, such as Type 120 Silicon Thermal Joint Compound (Wakefield Thermal Solutions, New Hampshire). This mounting arrangement and cooling structure optimizes both cost/complexity of the assembly and cooling efficiency and therefore also the lifetime/reliability of the solid state source.

[0015] According to one advantageous feature of the invention, the LED light sources may be mounted on a plane which is common to the planar surface of the heat sink on the single heat spreader plate, with the optical path length increasing with wavelength, e.g. the red LED has longest optical path, the blue LED has shortest optical path. LED light source is positioned at or near the focal point of a compound collector group consisting of an aspheric lens (e.g., Newport KPA040-C, Irvine, California), which collects the light from each LED light source. The collection efficiency of the aspheric lens may be enhanced by a field lens mounted between the LED and the aspheric lens. The aspheric lens projects a nearly collimated light beam from the LED onto a mirror or a dichroic filter (e.g. Semrock FF670-SDi01-25x36, Rochester, NY) positioned to reflect light at a right angle relative to the light projected by the aspheric lens into the combined light beam path. The dichroic filter is designed to reflect substantially all light at or above the wavelength of the LED emission and transmits the light of all shorter wavelengths. The power and position of each aspheric lens and the power and position of any field lens is adjusted as required for each LED to accommodate

the differences in optical path lengths. In this way, the etendue constraints with a linear arrangement of light sources can be managed and the capacity of the high NA lens in coupling the combined beam of light into an optical light guide can be maximized.

[0016] According to one advantageous feature of the invention, all optical elements not directly attached to the LED light sources (including all remaining collector lenses, reflective and dichroic mirrors, and collimating/condensing lenses) may be mounted in a mating mechanical enclosure. The enclosure may be fabricated from a single block of material such as aluminum, or similar material and may be machined or may be cast and machined as a single element. The mechanical enclosure may also be composed of multiple elements individually fabricated (e.g. machined) and assembled. The enclosure has a linear array of input ports matching the linear pattern of LED sources on the heat spreader plate - e.g., one input port for each LED light source - and a single output port. Once all optical components are mounted in the enclosure, the plate with the LED light sources is assembled to the enclosure input ports and a shutter that seals the exit aperture in the absence of a light guide is mounted placed on the output port. The enclosure is consequently fully sealed and the optical elements are protected against the ingress of dust and other contaminants.

[001 7] According to one advantageous feature of the invention, the illuminator may utilize a design without lenses and have instead polished reflective surfaces that propagate the light emitted by the LEDs. The light can then, as before, be combined using dichroic filters, with the combined light being coupled into the optical light guide, by means of reflective surfaces.

[0018] According to one advantageous feature of the invention, the illuminator may also contain other light sources, such as one or more diode lasers, that are coupled into the combined optical path. In one embodiment, the diode lasers

may be fiber coupled NIR lasers that emit in the 800 - 820 nm wavelength range suitable for fluorescence excitation of, for example, indocyanine green (ICG) or other NIR excited fluorescence agent. Alternatively or in addition, one or more of the fiber coupled diode lasers may produce 830 nm NIR light for purposes of mimicking the fluorescence of ICG. The NIR light emitted by the lasers may be coupled into the optical path by introducing an additional dichroic mirror that reflects NIR but transmits shorter wavelengths into the LED optical path. Alternatively, or in addition, the illuminator may contain one or more UV diode lasers for tissue autofluorescence excitation. These lasers may be coupled into the blue LED channel or directly coupled into the combined beam channel before the blue LED dichroic filter. The illuminator may also contain high powered NIR or UV LEDs instead of diode lasers.

[0019] The system also provides for imaging a conjugate plane from the collector group onto the light guide (i.e. fit a round cone to the light guide).

BRIEF DESCRIPTION OF THE DRAWING

[0020] Other features and advantages of the present invention will be more readily apparent upon reading the following description of currently preferred exemplified embodiments of the invention with reference to the accompanying drawing, in which:

[0021] FIG. 1 shows an LED package with a highly thermally conductive substrate;

[0022] FIG. 2 shows in a cut-away view an illuminator with a linear array of LEDs arranged on a heat spreader, with collection, combining and condensing optics;

[0023] FIG. 3 shows in a cut-away view an illuminator with a linear array of LEDs arranged on a heat spreader, with heat exchanger and fans; and

[0024] FIG. 4 shows an exemplary air flow pattern of the illuminator in an enclosure.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0025] Throughout all the figures, same or corresponding elements may generally be indicated by same reference numerals. These depicted embodiments are to be understood as illustrative of the invention and not as limiting in any way. It should also be understood that the figures are not necessarily to scale and that the embodiments are sometimes illustrated by graphic symbols, phantom lines, diagrammatic representations and fragmentary views. In certain instances, details which are not necessary for an understanding of the present invention or which render other details difficult to perceive may have been omitted.

[0026]Turning now to the drawing, and in particular to FIG. 1, there is shown an LED package including a substrate with high thermal conductivity having mounting holes for attachment to a heat spreader shown in FIG. 2. The LED package also includes electrical terminals for supplying electric power to the LEDs.

[0027] FIG. 2 shows in a cut-away view an illuminator with a linear array of LEDs arranged on a heat spreader, with collector optics, combining optics and condensing optics. The LEDS are arranged with increasing optical path lengths from the "White Light" output port. Collector optics, such as an aspheric lens and optionally a field lens, may be placed in front of each LED. The light from the red LED is reflected at a 90° angle by a mirror. Additional dichroic mirrors are placed in the combined beam path between this mirror and the "White Light" output port. These dichroic mirrors are designed to reflect, in the listed order, at a 90° angle light emitted by the exemplary long wavelength green LED (peak wavelength at ~ 530 nm and approximate FWHM bandwidth of +/- 40 nm), the exemplary short wavelength green LED (peak wavelength at ~515 nm and approximate FWHM

bandwidth of +/- 37 nm), and the exemplary blue LED (peak wavelength at ~ 460 nm and approximate FWHM bandwidth of +/- 25 nm), while transmitting the wavelengths already present in the propagating combined beam, i.e., red, red + long green, red + long green + short green. Light emitted by a laser can be suitably added to the combined beam.

FIG. 3 shows schematically the illuminator in a cut-away view with the linear array of LEDs on heat spreader, the LED-Laser heat exchanger and the LED-Laser heat exchanger fans.

[0028] FIG. 4 shows schematically an exemplary air flow pattern around the illuminator in the enclosure.

[0029] While the invention has been illustrated and described in connection with currently preferred embodiments shown and described in detail, it is not intended to be limited to the details shown since various modifications and structural changes may be made without departing in any way from the spirit and scope of the present invention. The embodiments were chosen and described in order to explain the principles of the invention and practical application to thereby enable a person skilled in the art to best utilize the invention and various embodiments with various modifications as are suited to the particular use contemplated.

CLAIMS

1. An apparatus for providing a light output to an optical guide for illumination of an imaged object, the apparatus comprising:

a plurality of solid state light-emitting sources each of which are independently powered and independently controlled, each light-emitting source emitting light at a wavelength which is different from the wavelength emitted by the other light-emitting sources;

a heat sink configured to thermally couple the plurality of solid state light-emitting sources and provide conduction of heat generated by the plurality of solid state light-emitting sources; and

optical elements to collect, collimate, and combine the emissions from the plurality of solid state light-emitting sources into a combined beam of light to be optically coupled to the light guide.

2. The apparatus of Claim 1, wherein the solid state light sources are selected from the group comprising light emitting diodes and diode lasers.

3. The apparatus of Claim 1, wherein the optical elements include a field lens and an aspheric lens configured to collect and collimate the emission form each of the plurality of solid state light-emitting sources.

4. The apparatus of Claim 1, wherein a dichroic filter is configured to couple the collimated emission from each of the plurality of solid state light-emitting sources into the combined beam of light directed along a common path to an output port.

5. The apparatus of Claim 4, wherein the relative optical path length associated with each one of the plurality of solid state light-emitting sources is based on the relative difference in wavelength.

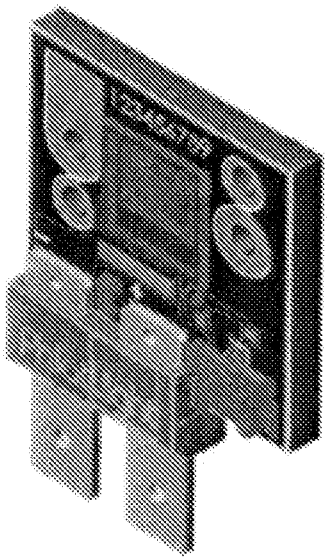


FIG. 1

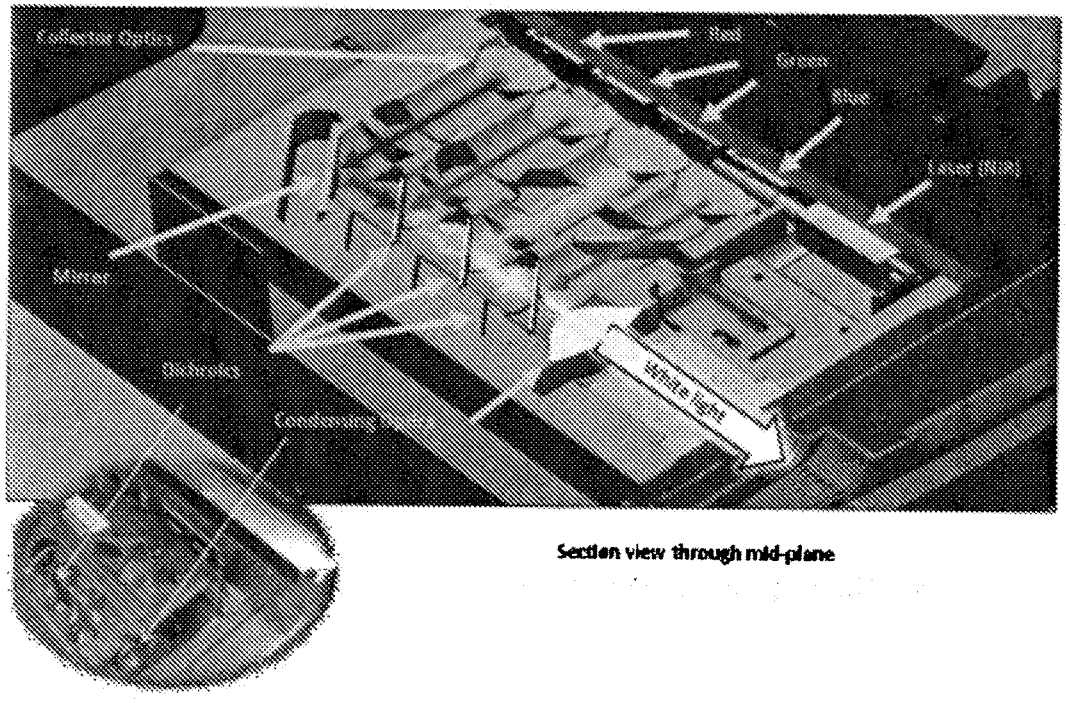


FIG. 2

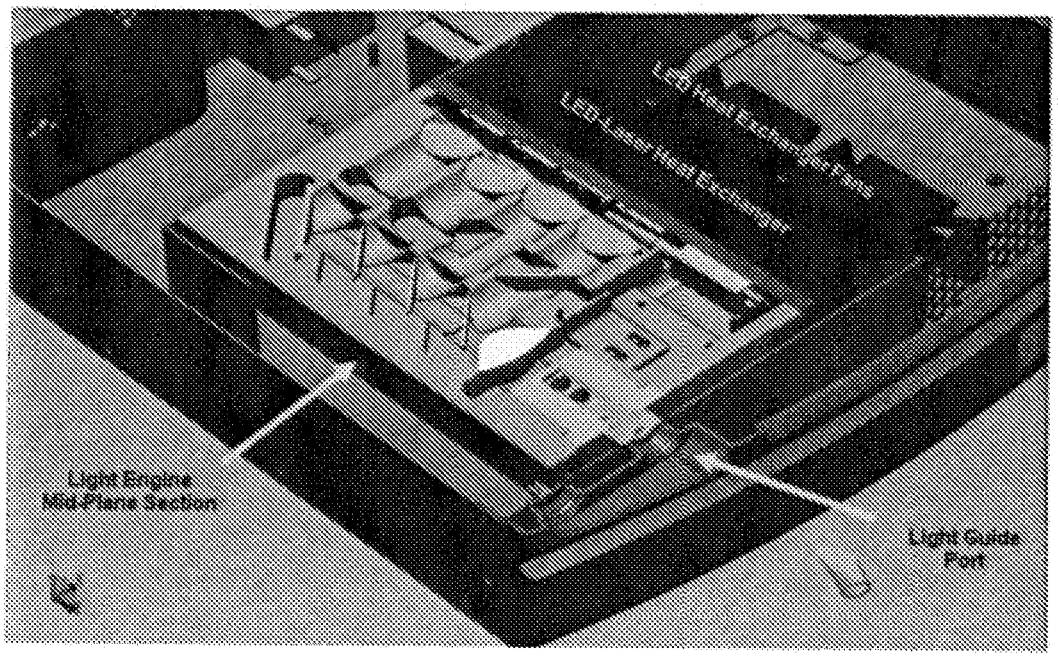

Light Engine
Mid-Plane Section
Light Guide
Port

FIG. 3

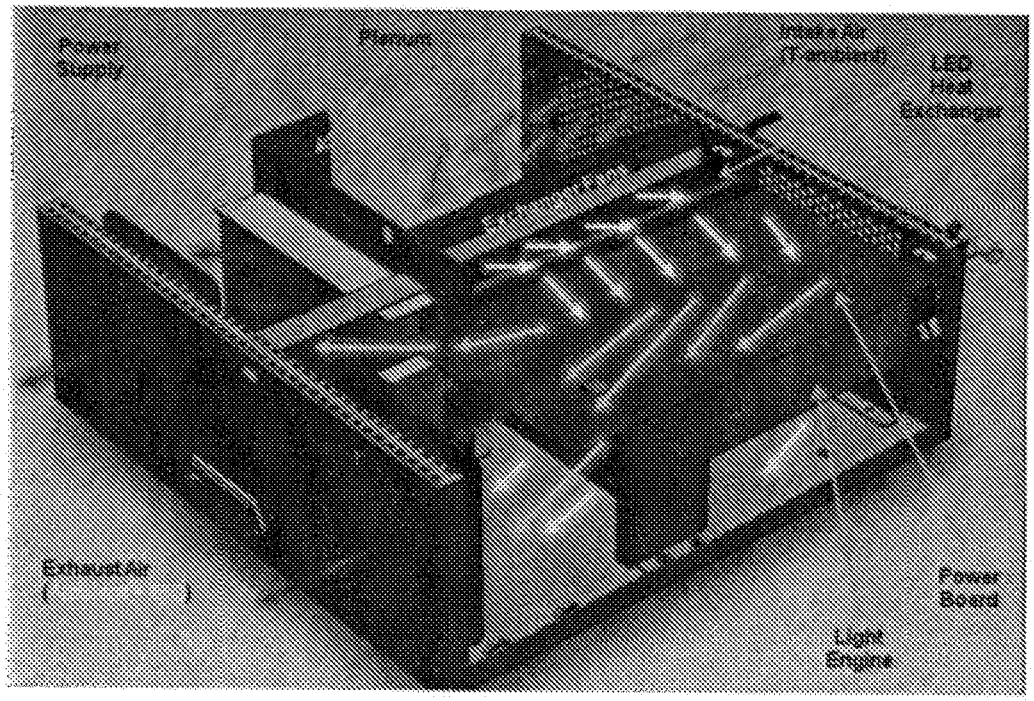

Power
Supply
Plenum
LED
Heat
Exchanger
Exhaust Air
Power
Board
Light
Engine

FIG. 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB20 12/000601

A. CLASSIFICATION OF SUBJECT MATTER
IPC: ***F21 V8/00*** (2006.01) , ***A61B 1/06*** (2006.01) , ***F21K 99/00*** (2010.01) , ***F21 V29/00*** (2006.01) , ***G02B 27/10*** (2006.01) , ***G02B 27/30*** (2006.01), ***H05B 37/02*** (2006.01)
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)
IPC: **F21V 8/00 , A61B 1/06, F21K 99/00, F21V 29/00 , G02B 27/10 , G02B 27/30, H05B 37/02**
EC: **A61B 1/06R6, F21V 29/22**

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

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
CANADIAN PATENT DATA BASE, EPODOC
keywords: light guide, heat sink, independent, power, LED, collimate, control, optic+ and dichroic

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 2006/0215406 A1 (THRAILKILL, W.) 28 September 2006 (28-09-2006) Fig. 1, Abstract, description page 2 and 3	1 to 3 4 and 5
Y	US 2008/0208006 A1 (FARR, M.) 28 August 2008 (28-08-2008) Fig. 11, 12 and 13, page 7	4 and 5
A	US 4953539 A (NAKAMURA, K. et al.) 04 September 1990 (04-09-1990) the entire document	1 to 5
A	US2004/0149998 A1 (HENSON, G. D. et al.) 05 August 2004 (05-08-2004) the entire document	1 to 5
A	US 2006/0002141 A1 (OUDERKTRK, A. J. et al.) 05 January 2006 (05-01-2006) the entire document	1 to 5
A	WO 94/13191 A1 (MOKHTARZAD, S. et al.) 23 June 1994 (23-06-1994) the entire document	1 to 5

[ ] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
17 July 2012 (17-07-2012)	03 August 2012 (03-08-2012)

Name and mailing address of the ISA/CA	Authorized officer
Canadian Intellectual Property Office Place du Portage I, CI 14 - 1st Floor, Box PCT 50 Victoria Street Gatineau, Quebec K1A 0C9 Facsimile No.: 001-819-953-2476	Malgorzata Samborski (819) 956-0759

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		JP2008505441A	21 February 2008 (21-02-2008)
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		US2007285943A1	13 December 2007 (13-12-2007)
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W09413191A1	23 June 1994 (23-06-1994)	AU5827094A	04 July 1994 (04-07-1994)