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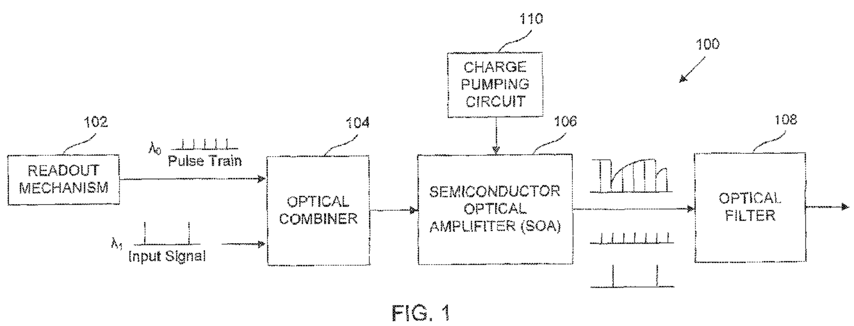

FIG. 1

(57) **Abstract**: An optical integration circuit includes a semiconductor optical amplifier (SOA), a readout mechanism coupled to the SOA, and an optical filter coupled to an output of the SOA. The SOA has a decaying response function and an input for receiving an optica! input signal having a first wavelength. The SOA is configured to output an optical signal representing a temporal integration of the optical input signal. The readout mechanism provides an optica! readout signal having a second wavelength to the SOA for measuring a state of the SOA. The optical filter is configured to receive the signal representing the temporal integration of the optical input signal and block optical signals having the first wavelength.

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OPTICAL INTEGRATION SYSTEM AND METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Patent Application No. 61/158,986, filed on March 10, 2009, which is incorporated by reference herein in its entirety.

FIELD OF DISCLOSURE

[0002] The disclosed system and method relate to optical computational systems. More specifically, the disclosed system and method relate to an optical system for performing an integration.

BACKGROUND

[0003] Optical signals have a high bandwidth which has led to them being incorporated in many signal processing applications. Accordingly, various optical circuits have been developed for performing various computations such as adding or subtracting. However, devices for performing complex signal processing computations, such as integration, have not been developed.

[0004] Accordingly, a device for performing optical integration is desirable.

SUMMARY

[0005] An optical integration circuit is disclosed including a semiconductor optical amplifier (SOA), a readout mechanism coupled to the SOA, and an optical filter coupled to an output of the SOA. The SOA has a decaying response function and an input for receiving an optical input signal having a first wavelength. The SOA is configured to output an optical signal representing a temporal integration of the optical input signal. The readout mechanism provides an optical readout signal having a second wavelength to the SOA for measuring a state of the SOA. The optical filter is configured to receive the signal representing the temporal integration of the optical input signal and block optical signals having the first wavelength.

[0006] A method is also disclosed in which an optical input signal and an optical signal of a pulse train are received at a semiconductor optical amplifier (SOA), an optical signal having an amplitude that is an integral of the optical input

signal is output, and the integrated optical signal is filtered to remove the optical input signal. The optical input signal has a first amplitude and a first wavelength, and the optical signal of the pulse train has a second amplitude and a second wavelength.

[0007] An optical integration circuit including an optical coupler, a semiconductor optical amplifier (SOA), and an optical filter is also disclosed. The optical coupler is configured to receive a first plurality of optical input signals each having a first wavelength and a second plurality of optical readout signals each having a second wavelength. The SOA is configured to receive an optical signal having the first and second wavelengths from the optical coupler and to output an optical signal representing a temporal integration of the optical input signal. The optical filter is coupled to an output of the SOA and is configured to receive the optical signal representing to temporal integration from the SOA and remove optical signals having the first wavelength.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. 1 is a block diagram of one example of an optical integration circuit.

[0009] FIG. 2A illustrates one example of input pulses received at an input of the optical integration circuit.

[0010] FIG. 2B illustrates one example of output pulses from the optical integration circuit in response to the receiving the input pulses illustrated in FIG. 2A.

[0011] FIG. 3A is an energy versus time graph showing the response of a semiconductor optical amplifier that receives a series of optical pulses.

[0012] FIG. 3B is an example oscilloscope trace of a plurality of optical signals of a pulse train.

DETAILED DESCRIPTION

[0013] Semiconductor optical amplifiers (SOAs) have been widely used in optical systems. SOAs experience cross-gain modulation (XGM) in which the gain of an SOA is depleted immediately after an optical pulse passes through the SOA and it then gradually increases over time. For many applications, the XGM of an SOA is undesirable and thus other optical amplifiers such as doped fiber amplifiers and Raman amplifiers are implemented. However, the system and method disclosed herein utilize the XGM of an SOA to advantageously provide an optical circuit for performing temporal integration of an optical input signal.

[0014] FIG. 1 is a block diagram of one example of an optical integration circuit or system 100. As shown in FIG. 1, the optical integration circuit 100 includes a readout mechanism 102 coupled to an input of optical coupler 104 having a plurality of inputs. An SOA 106 is coupled to an output of the optical coupler 104, and an optical filter 108 is coupled to an output of the SOA 106.

[0015] Readout mechanism 102 may be any device configured to provide one or more signals to SOA 106 for reading out a current state of SOA 106. For example, readout mechanism 102 may be a pulse train generator configured to provide an optical pulse train in which the optical signals have uniform wavelengths and amplitudes. A mode-locked ring fiber laser (MLL) configured to provide pulses on the order of picoseconds is one example of such an optical pulse train generator.

[0016] Optical coupler 104 may be any optical coupler configured to couple optical signals of different wavelengths and amplitudes in separate fibers into a single fiber. In one example, the optical coupler 104 has two inputs with one input receiving optical signals from readout mechanism 102 and the other input receiving an optical input signal. An example of a suitable fiber coupler 104 is a thermally tapered and fused pair of single-mode fibers, with the cores of the fiber pair coming into contact such that optical energy may be exchanged. If optical coupler 106 is a multiport coupler, it may be implemented as a tree of 2:1 couplers as will be understood by one skilled in the art. The optical signals of the pulse train may have a wavelength λ_0, and the optical input signals may have one or more wavelengths, λ_1, λ_2, etc., which are different from wavelength λ_0. Additionally, the optical input signals have an amplitude that is greater than the amplitude of the optical signals provided by the readout mechanism 102 such that the readout signals do not have a significant effect on the XGM of the SOA 106 as described below.

[0017] SOA 106 is coupled to an output of the optical coupler 104 and is configured to receive a combined optical input signal, which is a combination of the optical input signal and the readout signals from readout mechanism 102. One example of an SOA 106 is illustrated in FIG. 2. As shown in FIG. 2, the SOA 106 includes a semiconductor substrate 200, which may be a Group III-V compound substrate as will be understood by one skilled in the art. Substrate 200 may be an n-type substrate having an n-doped region 202 and a p-doped region 204. Metal layers 206 and 208 may be formed on a top and a bottom surface of the substrate 200. As shown in FIGS. 1 and 2, the charge pumping circuit 110 is coupled to SOA 106 for restoring the gain of SOA 106 through population inversion once the gain of the SOA 106 has been depleted. Charge pumping circuit 110 may be implemented as an electrical circuit in which a current is supplied to the substrate of the SOA 106, or charge pumping circuit 110 may be implemented as an optical circuit in which light is used to perform population inversion of the SOA 106.

[0018] Optical filter 108 is coupled to an output of the SOA 106 and is configured to pass the wavelengths of the readout signals and block the wavelengths of the optical input signals. For example, the optical filter 108 may be a short-pass, long-pass, or band-pass filter such as a thin film multi-layer dielectric filter, a fiber Bragg grating, or an arrayed waveguide grating, to name a few.

[0019] The operation of the optical integration circuit 100 is described with reference to FIG. 1. The optical input signals having a wavelength λ_1 are combined with readout signals provided by readout mechanism 102 having a wavelength λ_0 at optical coupler 104. The combined optical signal is output to SOA 106.

[0020] SOA 106 is pumped with electrons from the charge pumping circuit 110, which contributes to the gain of the SOA 106. When a pulse from one of the optical input signals having a wavelength λ_1 is received at the SOA 106, the gain of the SOA 106 is depleted due to the depletion of electrons, which are used to increase the amplitude of the optical input signals. The external pumping of the SOA 106 by the charge pumping circuit 110 causes the gain of the SOA 106 to gradually increase, but if another pulse is received from an optical input signal, then the gain of the SOA 106 will again be depleted. The recovery time of the gain of the SOA 106 is based on its carrier lifetime, τ_e, which functions as the integration time constant. Thus, the gains of SOAs having smaller carrier lifetimes will increase at faster rates than the gains of SOAs having larger carrier lifetimes. Consequently, the faster gain recovery results in less temporal integration as will be understood by one skilled in the art.

[0021] The SOA 106 outputs a signal representing a temporal integration of the optical input signal to optical filter 108. Optical filter 108 may be tuned such that the optical input signals having one or more wavelength λ_1 ,λ_2, etc., which are different from the wavelength, λ_0, provided by readout mechanism 102, are removed or otherwise filtered out. As described above, the optical filter 108 may be a long-pass, short-pass, or band-pass filter configured to pass the wavelengths of the readout signals while blocking the wavelengths of the optical input signals.

[0022] An optical integration circuit in accordance with FIG. 1 was designed and tested. The optical signals of the pulse train were generated using a supercontinuum generator with spectral slicing to generate optical signals having pulse widths of approximately 3 picoseconds full-width at half-maximum (FWHM).

[0023] SOA 106 was an Alcatel A1901SOA available from Alcatel-Lucent of Murray Hill, New Jersey. The resting potential of SOA 106, i.e., the maximum gain of the SOA when a control signal was not present, was equal to 43 fJ. A master pulse source having a 1.25 GHz mode-locked ring fiber laser ("MLL") was used to generate the optical input signals having a digital value of '01210' as illustrated in FIG. 3A. The digital output of the optical integration circuit 100 is shown in FIG. 3B.

[0024] FIG. 4A is an energy versus time graph illustrating the response of the SOA 106 to excitation by multiple pulses of optical input signals, which are shown in FIG. 4B. As shown in FIG. 4A, each input optical input pulse decreases the gain of the SOA 106 due to XGM. The gain of the SOA 106 gradually increases over time due to the charge pumping circuit 110 providing electrons to the SOA 106. The SOA carrier lifetime, τ_e, was approximately equal to 180 ps, but was adjustable between 100 to 300 ps by altering the pump current received from the charge pumping circuit 110.

[0025] Although the optical integration circuit and method have been described in terms of exemplary embodiments, they are not limited thereto. Rather, the appended claims should be construed broadly, to include other variants and embodiments of the circuit and method, which may be made by those skilled in the art without departing from the scope and range of equivalents.

What is claimed is:

1. An optical integration circuit, comprising:

a semiconductor optical amplifier (SOA) having a decaying response function and an input for receiving an optical input signal having a first wavelength, the SOA configured to output an optical signal representing a temporal integration of the optical input signal;

a readout mechanism coupled to the SOA for providing an optical readout signal having a second wavelength to the SOA for measuring a state of the SOA; and

an optical filter coupled to an output of the SOA, the optical filter configured to receive the signal representing the temporal integration of the optical input signal and block optical signals having the first wavelength.

2. The optical integration circuit of claim 1, further comprising a first optical coupler configured to receive the optical input signal having the first wavelength and the optical readout signal having the second wavelength provided by the readout mechanism, the optical coupler for coupling the optical input signal and the optical readout signal into a single fiber.

3. The optical integration circuit of claim 1, further comprising a charge pumping circuit coupled to the SOA supplying the SOA with electrons.

4. The optical integration of claim 1, wherein an amplitude of the optical input signal is greater than an amplitude of the optical readout signal.

5. The optical integration circuit of claim 1, wherein an integration time constant is approximately equal to a carrier lifetime of the SOA.

6. The optical integration circuit of claim 1, wherein the optical filter is a band-pass spectral filter tuned to filter the wavelength of the optical input signal.

7. A method comprising:

receiving an optical input signal and an optical readout signal at a semiconductor optical amplifier (SOA), the optical input signal having a first amplitude and a first wavelength and the optical readout signal having a second amplitude and a second wavelength;

outputting an optical signal representing a temporal integration of the optical input signal; and

filtering the signal representing the temporal integration of the optical input signal to remove the optical signals having the second wavelength.

8. The method of claim 7, wherein the first amplitude is greater than the second amplitude.

9. The method of claim 7, wherein the first wavelength is different from the second wavelength.

10. The method of claim 7, further comprising:

receiving the optical input signal and the optical readout signal at a first optical coupler;

combining the optical input signal and the optical readout signal; and

outputting a combined optical signal to a single fiber coupled to the input of the SOA, the combined optical signal including the optical input signal and the optical readout signal.

11. The method of claim 7, wherein an integration time constant is approximately equal to a carrier lifetime of the SOA.

12. The method of claim 7, wherein the SOA receives electrons from a charge pumping circuit.

13. An optical integration circuit, comprising:

an optical coupler configured to receive a first plurality of optical input signals each having a first wavelength and a second plurality of optical readout signals each having a second wavelength;

a semiconductor optical amplifier (SOA) configured to receive an optical signal having the first and second wavelengths from the optical coupler and to output an optical signal representing a temporal integration of the optical input signal; and

an optical filter coupled to an output of the SOA, the optical filter configured to receive the optical signal representing to temporal integration from the SOA and remove optical signals having the first wavelength.

14. The optical integration circuit of claim 13, further comprising a charge pumping circuit coupled to the SOA for increasing a carrier density of the SOA.

15. The optical integration circuit of claim 13, wherein the optical filter is an optical band-pass filter configured to block optical signals having the first wavelength and pass optical signals having the second wavelength.

16. The optical integration circuit of claim 13, wherein the optical input signal has a first amplitude that is greater than a second amplitude of the optical readout signals.

17. The optical integration circuit of claim 13, wherein an integration time constant is approximately equal to a carrier lifetime of the SOA.

18. The optical integration circuit of claim 13, wherein the optical filter is one of a long-pass filter or a short-pass filter for blocking the optical signals having the first wavelength and passing optical signals having the second wavelength.

19. The optical integration circuit of claim 13, wherein a gain-recovery time of the SOA is two-orders of magnitude greater than a pulse width of each of the optical readout signals.

20. The optical integration circuit of claim 19, wherein the pulse width of each of the optical readout signals is on an order of picoseconds.

REPLACEMENT SHE

1/3

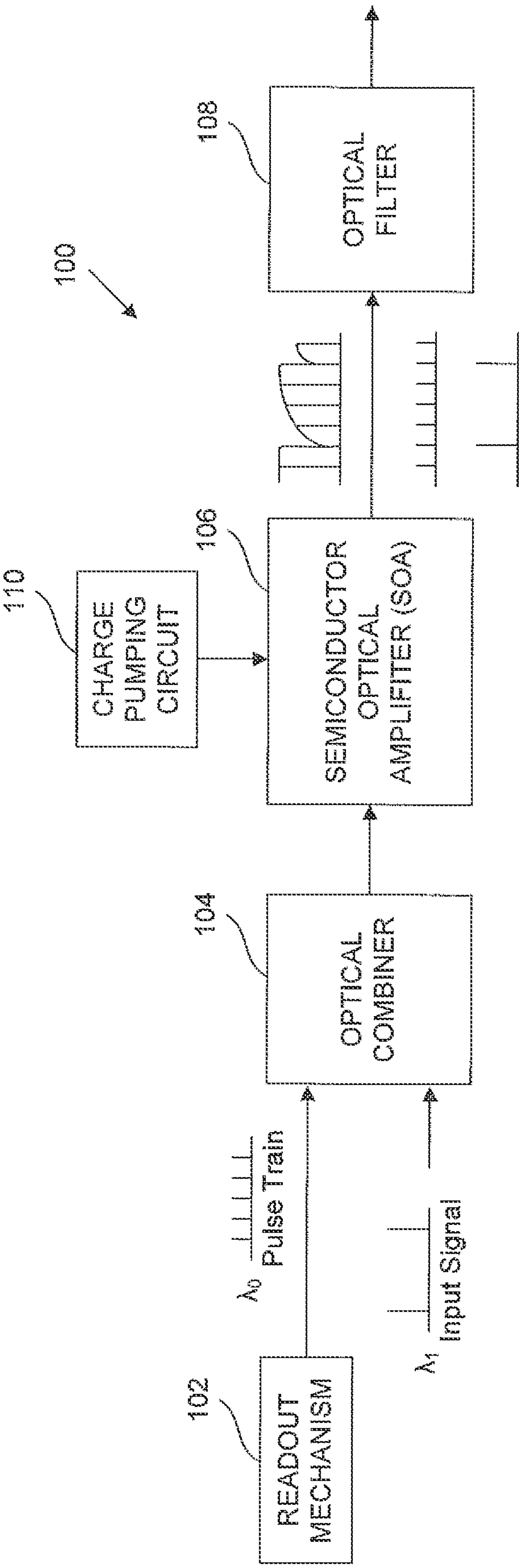

FIG. 1

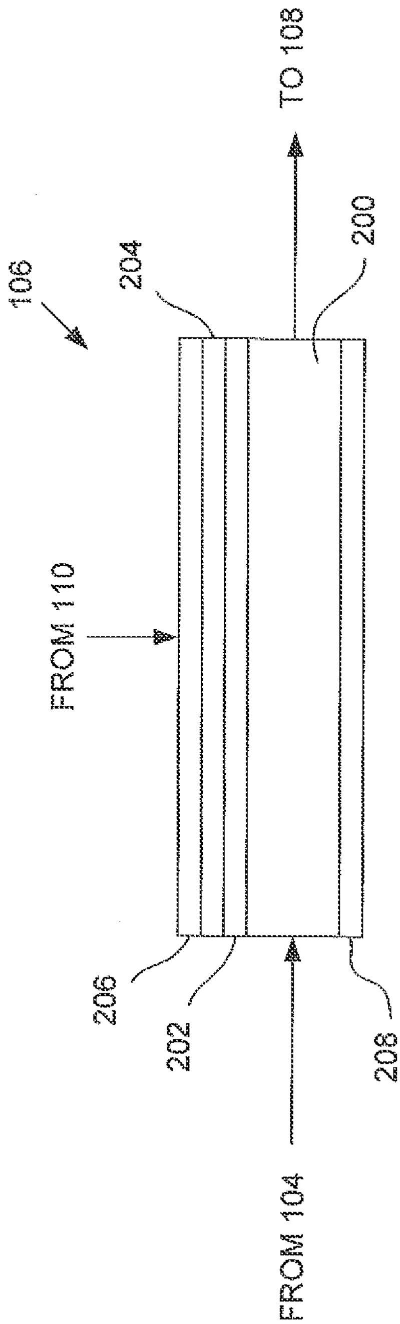

FIG. 2

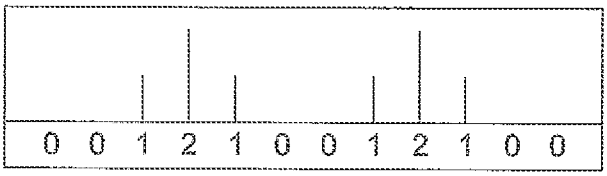

FIG. 3A

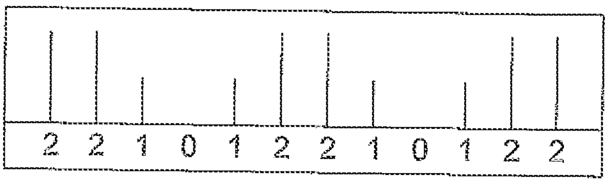

FIG. 3B

REPLACEMENT SHEET

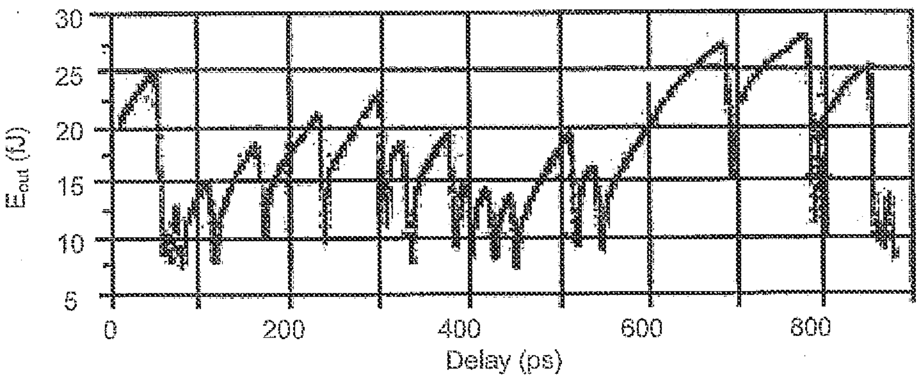

FIG. 4A

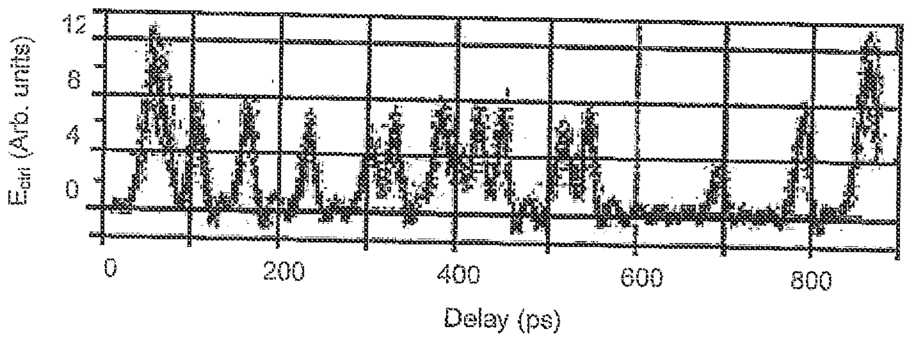

FIG. 4B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2010/026830

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - H04B 10/16 (2010.01)
USPC - 398/180
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(8) - H04B 10/16; G01S 13/00; G02B 6/12 (2010.01)
USPC - 398/180; 342/195; 385/14

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
USPTO EAST System (US, USPG-PUB, EPO, DERWENT), MicroPatent

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 6,046,841 A (MAHGEREFTEH et al) 04 April 2000 (04.04.2000) entire document	3,12,14
Y	US 7,394,990 B1 (YEE) 01 July 2008 (01.07.2008) entire document	1-20
Y	US 2006/0049981 A1 (MERKEL et al) 09 March 2006 (09.03.2006) entire document	1-20
Y	US 2009/0027689 A1 (YUN et al) 29 January 2009 (29.01.2009) entire document	1-20
Y	US 6,337,762 B1 (UENO) 08 January 2002 (08.01.2002) entire document	5,11, 17
A	US 6,556,735 B1 (KATO) 29 April 2003 (29.04.2003) entire document	1-20
A	US 7,265,712 B2 (MERKEL et al) 04 September 2007 (04.09.2007) entire document	1-20
A	US 2007/0189662 A1 (NAKAMURA) 16 August 2007 (16.08.2007) entire document	1-20
A	US 5,946,129 A (XU et al) 31 August 1999 (31.08.1999) entire document	1-20

☐ Further documents are listed in the continuation of Box C. ☐

* 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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"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
26 April 2010	10 MAY 2010

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774