Title: SEMICONDUCTOR LASER WITH APERIODIC PHOTONIC LATTICE

Abstract: A semiconductor laser and method for selecting laser frequency emission from the semiconductor laser are disclosed. The semiconductor laser provides selectable frequency emission and includes an aperiodic photonic lattice.
SEMICONDUCTOR LASER WITH APERIODIC PHOTONIC LATTICE

The present invention relates to a method and apparatus for providing a semiconductor laser. In particular, but not exclusively, the present invention relates to a terahertz quantum cascade laser arranged for laser emission at selectable frequencies.

Semiconductor devices have become important sources for generating electromagnetic radiation for a wide range of uses. Semiconductor lasers in particular are well known and have many applications. In recent years semiconductor lasers have been produced which provide compact lasers able to provide relatively high output power at definable frequencies. One type of semiconductor laser is the quantum cascade laser (QCL).

The quantum cascade laser (QCL) is a strikingly successful example of electron wavefunction engineering, with its active region comprising a superlattice of strongly coupled semiconductor quantum wells. Adjusting the composition and thickness of the constituent semiconductor layers allows the electronic and optical properties to be tailored by controlling the local electron confinement both spatially and energetically.

For photon confinement, conventional QCLs use simple Fabry-Perot (FP) cavities, formed by partially transmitting mirrors at the ends of laser stripes. As a consequence, a number of competing lasing modes exist, leading to instability and poor spectral purity. In contrast, a precisely defined frequency, free from jitter and mode hopping, is required for many applications, including atmospheric sensing, where the emission frequency needs to be tuned to a specific absorption line in the rotational energy spectra of a gas molecule. It is therefore highly desirable to engineer the photonic confinement of a QCL in a systematic manner. Indeed, a number of researchers have patterned the surface of a QCL with a periodic lattice, forcing the laser to operate at a single frequency determined by the lattice period and the effective index of the medium. Whilst demonstration of a single lasing frequency is a promising start for gas spectroscopy applications, there is a real need to be able to either tune this frequency, or to have a device operating at two, or more, well defined frequencies. In order to meet these requirements further control of the device photonic band properties is required.

The terahertz (THz) region of the electromagnetic spectrum has generally been under-exploited due to difficulties in producing coherent sources. Terahertz radiation is used for a number of applications including spectroscopy and in particular gas spectroscopy
since many gases are strong absorbers of terahertz radiation. Terahertz imaging is another application where a terahertz radiation source would be useful. This is because many materials which reflect visible light will transmit terahertz (THz) radiation. Unfortunately at present there is no source of terahertz (THz) radiation which is compact, narrow band and tunable.

It is an aim of the present invention to at least partly mitigate the above-mentioned problems.

It is an aim of embodiments of the present invention to provide a semiconductor laser for providing selectable frequency emission.

It is an aim of embodiments of the present invention to provide a method for manufacturing a semiconductor laser for providing selectable frequency emission.

It is an aim of embodiments of the present invention to provide a quantum cascade laser operable in the terahertz frequency range which can provide multi-frequency emission either separately or simultaneously.

According to a first aspect of the present invention there is provided a semiconductor laser for providing selectable frequency emission, comprising:

an aperiodic photonic lattice.

According to a second aspect of the present invention there is provided a method for selecting laser frequency emission from a semiconductor laser, comprising the steps of:

providing a semiconductor laser comprising an aperiodic lattice structure;

determining one or more desired frequencies of emission for said laser;

selecting a parameter for said laser responsive to said step of determining one or more desired frequencies of emission; and

providing said parameter at said laser at the selected value.

According to a third aspect of the present invention there is provided a method for manufacturing a semiconductor laser for providing selectable frequency emission, comprising the steps of:

providing a semiconductor laser comprising an aperiodic photonic lattice.
Embodiments of the present invention provide a semiconductor laser able to provide selectable frequency emission. Certain embodiments of the present invention provide a quantum cascade laser emitting in the terahertz (THz) frequency range which can emit radiation at more than one selectable frequency. The frequency or frequencies of emission can be selected relatively simply by adjusting a pumping current provided to the laser.

Embodiments of the present invention will now be described hereinafter by way of example only, with reference to the accompany drawings in which:

15 Figure 1 illustrates a schematic view of a semiconductor laser;

Figure 2 illustrates a schematic view of a semiconductor laser;

Figure 3 illustrates how perturbations of an active area of the laser can be introduced.

Figure 4 illustrates slits in an active region of a semiconductor laser;

Figure 5 illustrates spatial mode profiles;

20 Figure 6 illustrates an image of a device;

Figure 7 illustrates an FP spectrum;

Figure 8 illustrates components due to a single defect photonic lattice microcavity;

Figure 9 illustrates voltages – current and light – current characteristics; and

Figure 10 illustrates frequency of emission as a function of drive current.

In the drawings like reference numerals refer to like parts.

Throughout this specification reference will be made to terahertz (THz) radiation. It will be understood that the frequency range of terahertz radiation lies in the gap between electronics and photonics. As such the frequency range is around $10^{12}$ to $10^{13}$ Hertz. It is to be understood that embodiments of the present invention are not restricted to the
terahertz frequency range but are broadly applicable to the generation of electromagnetic radiation via a semiconductor laser device.

One example of a semiconductor laser is a quantum cascade laser (QCL). A QCL has been described by Köhler et al in Nature, Vol 417, 9 May 2002 p156-159 which is incorporated herein by reference. Figure 1 illustrates a THz QCL in accordance with an embodiment of the present invention. The THz QCL (10) consists of an 11.2-μm-thick GaAs/Al_{0.15}Ga_{0.85}As chirped superlattice active region (11) with surface-plasmon optical confinement. In brief, a buried 800-nm-thick highly doped n^+ GaAs layer (12) (doping density ~2×10^{18} cm^{-3}) provides the lower plasmonic boundary between the active medium and the undoped GaAs substrate (13) and also acts as a lower ohmic contact. A 200-nm-thick n^+ GaAs layer (14) (doping density ~5×10^{18} cm^{-3}), and a Ti/Au layer (15) on top of the active region, confines the laser mode from the upper side, with a standard low resistance ohmic contact made to the GaAs layer. The wafer is processed into a 90μm-wide, 2.2-mm-long, laser ridge stripe geometry having width x as shown better in Figure 2, and soldered onto copper blocks for heat sinking. The whole packaged laser is inserted inside a focussed ion beam etching system (FEI Nova 200 NanoLab), where a finely focused (~7 nm) beam of highly energetic (30 keV) gallium ions, at 1 nA beam current, introduce discrete reflection sites into the laser stripe by etching narrow, sub-wavelength (1.2 μm width) slits (30) through the top metal contact (15) and upper n^+ GaAs layer into the first few layers of the active region. These form a photonic lattice within the QCL. A single-defect was introduced as a ‘gap’ (31) of length 7.5Å between two uniform lattice sections of length 14Å, where \( \Lambda = 9.36 \) μm is the periodicity of the photonic lattice. The defect can be seen as a break in the periodicity, thereby forming a microcavity. To achieve multiple wavelength operation, for example, the dual wavelength operation described later one or more of, three parameters can be adjusted simultaneously, namely: the available Fourier components of the photonic lattice; the detuning of both the gain peak frequency of the THz QCL and the Bragg frequency; and the pumping current.

It will be understood that in accordance with further embodiments of the present invention other parameters associated with the semiconductor device can be selected and set so as to select a frequency of emission and/or dual or multi wavelength operation. For example a temperature of the semiconductor device or level of external optical excitation or other parameters may be varied.
Figure 4a illustrates how multiple slits (30) may be formed in a row at an upper surface of the active region of a semiconductor laser. Figure 4b illustrates how the slits penetrate the top metal contact (15) and upper GaAs layer (14) and etch a small distance y into an upper surface region of the active region (11). It will be understood that the etch depth y into the active region can be selected between a distance in which hardly any active material is removed to a greater depth. The motivation is to maximize the effect of photonic lattice without compromising too much with the resulting loss due to the photonic lattice. With this in mind, the etch depth will depend on the precise laser structure. For the devices given in this specific example, i.e. for QCLs described in Köhler et al in Nature Vol 417, 9 May 2002 p156-159, the etch depth is less than one micron. Figure 4b illustrates an end of a first periodic lattice section formed by the slits illustrated. The slits are formed in an upper surface (40) across a first region thus providing periodic perturbations into a section of active region underlying the region in which the slits are formed. A gap (31) which provides a break in the slits provides a microcavity region in which the active region is unperturbed. A further periodic array of slits is formed on the other side of the microcavity as illustrated in Figure 3. The slits of the further array of slits forms a second periodic lattice section in the active region of the semiconductor laser. By providing two sets of periodic lattice section separated by a break in periodicity, an aperiodic photonic lattice is generated. Whilst the aperiodic photonic lattice has been described hereinbefore as being produced by formation of slits, it will be understood that embodiments of the present invention are not restricted to the use of slits in an upper surface of active region. Rather any methodology for repeatedly varying an effective refractive index of sections of active region underlying an upper surface of the active region may be employed. For example, compressive and tensile elements may be provided on an upper surface. Other ways include: ion implantation, impurity diffusion, metal layer deposition, application of local electric field etc.

The calculated spatial mode profiles for ridge waveguide geometries are shown in Figures 5a and 5b for the (a) unperturbed and the (b) perturbed (slit) regions of the photonic lattice. The calculation first uses a Drude model for the refractive indices of the separate semiconductor layers, and then a fully-vectorial, finite element mode solver to calculate effective indices, mode profiles, loss factors and confinement factors for the guided modes.

Figure 6 illustrates a scanning electron micrograph of a processed device. Note the defect of length 7.5Λ between two uniform lattice sections of length 14Λ where Λ= 9.36 μm. (ii) Modelled spatial mode profiles in the (a) unperturbed (n_{eff} = 3.660) and
(b) slit (600 nm etch depth) \( n_{\text{eff}} = 3.530 \) regions of the waveguide.

For the unperturbed region, an average effective refractive index can be calculated as \( n_{\text{eff}} = 3.660 \), for the whole ridge structure at an emission frequency of 4.4 THz; in the slit region we find \( n_{\text{eff}} = 3.530 \) for a 600 nm etch depth. Thus an estimate the effective index value for the photonic lattice section is:

\[
n_{\text{eff}} = 3.644 \text{ from } \Delta n_{\text{eff}}^2 = l_1 n_{\text{eff}}^2 + l_2 n_{\text{eff}}^2 ,
\]

where \( l_1 = 8.16 \mu m \) (unperturbed section length) and \( l_2 = 1.2 \mu m \) (slit width). Estimating \( \kappa L \) (where \( \kappa \) is the coupling coefficient and \( L \) the lattice length) for a rectangular shaped lattice by an effective index approximation, i.e., considering just the difference in effective indices of the two modes,

\[
\Delta n_{\text{eff}} = n_{\text{eff}1} - n_{\text{eff}2} ,
\]

we obtain

\[
\kappa L = \left(2 f_B \Delta n_{\text{eff}} / c \right) (35.5 \Lambda) = 1.3 ,
\]

where \( c \) is the speed of light in vacuum. It is to be noted that although the change of index in this example is abrupt it can be smoothed out either by using a linear function or non-linear function such as a parabolic or cosine function. The actual \( \kappa L \) value, however, is expected to be higher, as this estimate does not take into account the perturbation of the spatial mode profiles between the perturbed and the unperturbed regions of the lattice as shown in Figures 5a and 5b, and the consequent impedance mismatch between the modes. Furthermore, owing to the relatively high \( \kappa L \) value, compared to the critical coupling condition (\( \kappa L = 1 \)), optical power distribution becomes localized in the centre of the cavity (a longitudinal spatial hole-burning effect). Moreover, the microcavity, being electromagnetically resonant, is also able to trap light causing strong field confinement of the resonator mode which falls off exponentially into the periodic structure on either side. This improves the nonlinearity resulting from the interaction of the longitudinal-non-uniform mode intensity with the injected carrier distribution. The resulting non-uniform carrier density gives rise to a non-uniform active layer refractive index, which in turn alters the phasing of the lattice.
A FP cavity of length $L_c$ quantizes the Fourier ($k$-space) space into discrete points, defined by

$$\Delta k = 1/[2L_c(n_{\text{eff}}\lambda n_{\text{eff}}/d\lambda)] = 1/2L_c n_g,$$

where $n_g = 4.33$ is the group index of the surface plasmon waveguide, calculated from the measured FP spectrum shown in Figure 7, where $L_c = 2.2$ mm. In the absence of any defects, periodic lattices provide only one strong Fourier component of effective index at the highest spatial frequency $2\pi/\Lambda n_{\text{eff}}$, the Nyquist frequency. This is responsible for forming a single Bragg stop-band of frequency width $2\Delta f$, centred at

$$f_0 = c/2\lambda n_{\text{eff}}, \text{ where } \Delta f = kc/2\pi n_g.$$

When realized within a FP cavity of length $L_c$, this stop-band modifies the underlying FP mode structure by enhancing FP resonances close to the band edge frequencies ($f_0 \pm \Delta f$) and diminishing resonances within the stop-band frequencies. The single-defect photonic-lattice-microcavity, however, provides two strong symmetric Fourier components, closely spaced centred on the Nyquist frequency. This is illustrated in Figure 8. The original FP mode structure is therefore perturbed, through the Bragg stop-band formation mechanism, at two, closely-spaced, frequency points centred at $f_0$. The single-defect lattice perturbation therefore has richer spectral features compared with a periodic lattice. For example, in addition to the band edge frequency resonant states at $f_0 \pm \Delta f$, it also provides a strong resonance at $f_0$. It can be shown that for the structure shown in Figure 3, formed within a lasing cavity, the threshold gain of the resonant mode at frequency $f_0$ is low compared with any other modes. Other resonant modes at $f_0 \pm \Delta f$, allowed by FP quantization, could however achieve the required threshold gain owing to any non-zero detuning of the gain peak frequency and the Bragg frequency $f_0$, which further benefits from some degree of control through varying the applied bias pumping current owing to the non-linearity of the effective index. This dynamic makes, in particular, it more easy for the high frequency resonant mode to reach lasing.

To investigate the effect of a single-defect photonic-lattice microcavity, the THz QCL was mounted onto the cold finger of a liquid-helium-cooled continuous flow cryostat equipped with polyethylene windows, and was driven at 10 kHz with a 25% duty cycle. Spectra were recorded with a Bruker Fourier-transform infrared spectrometer in rapid scan mode with a
resolution of 0.25 cm⁻¹. A helium-cooled silicon composite bolometer was used for THz detection. The electrical (V-I) and light-current (L-I) performance of two QCLs, unpatterned and patterned, are shown in Figures 9a and 9b. In both figures, which show similar V-I and L-I characteristics, the estimated power from each facet of the laser is plotted, as estimated from the detector’s responsivity.

Figures 9a and 9b illustrate comparative voltage –drive current (V-I) and light – drive current (L-I) characteristics for 2.2-mm-long 4.44 THz FP QCLs, where (a) an unpatterned device and (b) single-defect photonic-lattice-microcavity device. (ii) Emission spectra (at 10 K) are shown for above devices. (a) Unpatterned device shows multi-mode FP spectrum; \( n_g = 4.33 \) is calculated from the mode spacing. (b) Single-defect photonic microcavity device shows single mode emissions at 4.400 THz (red, SMSR= 25 dB) and at 4.446 THz (violet, SMSR= 21 dB) and simultaneous dual-mode emissions (black, SMSR= 18dB) at 4.400 and 4.446 THz, which were measured at current densities 1.616 \( J_{th} \), 1.871 \( J_{th} \) and 1.818 \( J_{th} \), respectively, where \( J_{th} (= 250 \text{ A/cm}^2) \) is the threshold current density for the 4.4 THz mode. FP spectrum was taken at current density 1.636 \( J_{th} \). All measurements were performed in pulsed mode at 10 kHz with a 25% duty-cycle.

Figure 8 shows the emission spectra of the THz microcavity QCL at three current densities 1.616 \( J_{th} \), 1.818 \( J_{th} \), and 1.871 \( J_{th} \). It shows single-mode lasing at frequency \( f_1 \), simultaneous dual mode lasing at frequencies \( f_1 \) and \( f_2 \), and single mode lasing again at frequency \( f_2 \) respectively, where \( J_{th} (= 250 \text{ A/cm}^2) \) is the threshold current density for the low frequency \( (f_1) \) single mode. The emission frequencies are \( f_1=4.400 \text{ THz and f}_2=4.446 \text{ THz} \). At low to moderate bias, the gain peak frequency is such that the most prominent resonant states (at \( f_1 = f_2 \)) is enhanced and starts to lase, resulting in a single longitudinal mode operation at low frequency. For higher currents, the gain peak frequency shifts towards a higher frequency resonant point (owing to the Stark shift) resulting in a further single longitudinal mode at the higher frequency of \( f_2 = f_2 + \Delta f \). At intermediate bias, both frequencies contribute to the final mode patterns, whilst at high biases, only the higher frequency mode, \( f_2 \) is obtained. For the \( f_1 \), \( f_1 \) & \( f_2 \) and \( f_2 \) lasing cases, the side mode suppression ratios (SMSRs), relative to any other side modes, are better than 25 dB, 18 dB and 21 dB, respectively. For dual-mode \( (f_1 \) & \( f_2 \)) operation, the power of the two modes has been adjusted to be within about 0.02 dB of each other.
Figure 10 illustrates current density dynamics at 10 K of the dual-mode lasing spectrum of the single-defect photonic-microcavity THz QCL.

It is noted that (a) the Bragg frequency $f_B = c/2\Lambda n_{eff} = f_1 = 4.400$ THz, provides an effective refractive index value of $n_{eff} = 3.642$ and (b) the dual mode frequency separation $\Delta f = k c 2 \pi n_g = 46$ GHz, provides $kL \approx 1.4$. Both of these are in excellent agreement with the theoretical estimation. Furthermore, by adjusting the bias current through the device, individual amplitude of the two modes can be precisely controlled. Figure 10 shows this dynamic behaviour as the driving current density varies between 1.616 $J_{th}$ to 1.871 $J_{th}$.

Embodiments of the present invention provide a terahertz frequency quantum cascade laser that operates simultaneously at two frequencies ($f_1$ and $f_2$). One possible design is based on a single-defect photonic-lattice-microcavity structure engraved by a focused ion beam in a 2.2-mm-long Fabry-Perot laser. In embodiments of the present invention the device output can be tuned smoothly and controllably, by changing the applied driving bias, from single-mode emission at $f_1$, through to single-mode emission at $f_2$, via a dual-mode lasing regime.

Embodiments of the present invention provide a single-defect photonic-lattice-microcavity structure within a chirped superlattice THz frequency QCL waveguide to achieve THz lasing at two frequencies ($f_1$ and $f_2$) simultaneously. By changing the applied driving current, it is possible to switch the laser operation from a single mode at $f_1$, to dual mode, to single mode at $f_2$. The dual mode operation is an outcome of the interactions between the Fabry-Perot cavity, the photonic lattice-microcavity and a spatial hole burning effect.

Throughout the description and claims of this specification, the words "comprise" and "contain" and variations of the words, for example "comprising" and "comprises", means "including but not limited to", and is not intended to (and does not) exclude other moieties, additives, components, integers or steps.

Throughout the description and claims of this specification, the singular encompasses the plural unless the context otherwise requires. In particular, where the indefinite article is used, the specification is to be understood as contemplating plurality as well as singularity, unless the context requires otherwise.
Features, integers, characteristics, compounds, chemical moieties or groups described in conjunction with a particular aspect, embodiment or example of the invention are to be understood to be applicable to any other aspect, embodiment or example described herein unless incompatible therewith.
CLAIMS

1. A semiconductor laser for providing selectable frequency emission, comprising:
   an aperiodic photonic lattice.

2. The laser as claimed in claim 1 further comprising an active region comprising
   said aperiodic photonic lattice.

3. The laser as claimed in claim 1 or claim 2, wherein said laser comprises:
   a first periodic lattice section;
   a second periodic lattice section; and
   a middle section disposed between said first and second periodic lattice sections
   and providing a break in periodicity at an end of each of the first and second periodic
   lattice sections.

4. The laser as claimed in claim 3 wherein said first and second periodic lattice
   sections share a common periodicity.

5. The laser as claimed in claim 3 or claim 4 wherein said middle section comprises
   a microcavity.

6. The laser as claimed in claim 3 wherein each said first and second periodic
   lattice section comprises an active region.

7. The laser as claimed in claim 3, further comprising:
   said active region comprises an upper surface having a first region including
   periodic perturbations, a section of said active region underlying said first region
   comprising said first periodic lattice section, and a second region including periodic
   perturbations, a section of said active region underlying said second region comprising
   said second periodic lattice section.

8. The laser as claimed in claim 7, further comprising:
   said upper surface of the active region comprises a middle region located
   between said first and second regions, a section of said active region underlying said
   middle region comprising said middle section.
9. The laser as claimed in claim 8, further comprising:
said periodic perturbation comprises a periodic array of slits formed in the upper
surface of active material comprising said active area.

10. The laser as claimed in claim 9, further comprising:
said middle region of said upper surface includes no slits.

11. The laser as claimed in claim 3, further comprising:
said first and second periodic lattice sections each comprise a section of active
area having sub-sections in which an effective index of refraction is repeatedly
alternated between a first and second effective index of refraction value.

12. The laser as claimed in any one of claims 1 to 11, further comprising:
a power source for providing a pumping current to said semiconductor laser at
selectable pumping current values, a selected pumping current value determining at
least one frequency of emission of the laser.

13. The laser as claimed in any one of claims 1 to 12, further comprising:
said laser is arranged to provide dual mode laser emission at two frequencies
simultaneously when a pumping current of said laser is set at a predetermined value.

14. The laser as claimed in any preceding claim wherein said laser is a quantum
cascade laser.

15. The laser as claimed in claim 14 wherein said laser emits radiation in the
terahertz frequency range.

16. The laser as claimed in claim 3 wherein said first, middle and second periodic
lattice sections comprise a chirped superlattice.

17. A method for selecting laser frequency emission from a semiconductor laser,
comprising the steps of:
providing a semiconductor laser comprising an aperiodic lattice structure;
determining one or more desired frequencies of emission for said laser;
selecting a value of a parameter for said laser responsive to said step of determining one or more desired frequencies of emission; and providing said parameter at said laser at the selected value.

18. The method as claimed in claim 16, further comprising providing an active region comprising said aperiodic lattice structure.

19. The method as claimed in claim 17 further comprising selecting a pumping current value.

20. The method as claimed in claim 17 or claim 18, further comprising the steps of: selecting a pumping current to provide simultaneous emission from said laser at multiple frequencies.

21. The method as claimed in any one of claims 19 or 20, further comprising the steps of: subsequent to said step of selecting a pumping current, selecting a further pumping current; and providing pumping current to said laser at said further pumping current thereby providing laser emission at a further frequency of emission.

22. The method as claimed in any one of claims 17 to 21, further comprising the steps of: said step of providing a semiconductor laser comprises providing a quantum cascade laser.

23. The method as claimed in any one of claims 17 to 22, further comprising the steps of: said method comprises selecting laser frequency emission in the terahertz frequency range.

24. A method for manufacturing a semiconductor laser for providing selectable frequency emission, comprising the steps of: providing a semiconductor laser comprising an aperiodic photonic lattice.
25. The method as claimed in claim 24, further comprising the steps of providing a semiconductor laser active region comprising said aperiodic photonic lattice.

26. The method as claimed in claim 25 further comprising the steps of:

- said step of providing an active region comprises providing a first periodic lattice section, a second periodic lattice section and a break in periodicity between the first and second periodic lattice sections.

27. The method as claimed in claim 25 or claim 26, further comprising the steps of:

- said step of providing an active region comprises providing an active medium and etching slits in an upper surface of the active medium.

28. The method as claimed in claim 25, further comprising the steps of:

- etching a first array of slits having a first periodicity and a second array of slits having a second periodicity, an area of the upper surface of the active medium between the first and second array of slits remaining unetched.

29. The method as claimed in claim 25, further comprising the steps of:

- forming a doped layer over the active medium and a metal layer over the doped layer and etching through the doped layer and metal layer when said slits are etched.

30. The method as claimed in any one of claims 24 to 29, further comprising the steps of:

- providing a substrate;

- forming a lower doped layer on the substrate; and

- forming the active region on the lower doped layer.

31. The method as claimed in claim 27, further comprising the steps of:

- prior to said step of etching slits, forming the active region as a laser ridge stripe topology.

32. A method substantially as hereinbefore described with reference to the accompanying drawings.

33. Apparatus constructed and arranged substantially as hereinbefore described with reference to the accompanying drawings.
Fig. 1
Fig. 3
Fig. 7

Fig. 8

Fig. 9a

Fig. 9b
Fig. 10
INTERNATIONAL SEARCH REPORT

PCT/GB2007/002820

A. CLASSIFICATION OF SUBJECT MATTER
INV. HO1S5/10
ADD. HO1S5/34

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)
HO1S

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 practical, search terms used)
EPO-Internal, WPI Data, INSPEC, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>US 6 778 581 B1 (LIPSON JAN [US]) 17 August 2004 (2004-08-17) column 6, line 13 - column 7, line 9; figures 4,5</td>
<td>1,2,17, 18,24,25</td>
</tr>
</tbody>
</table>

Further documents are listed in the continuation of box C.

* Special categories of cited documents:
  *A* document defining the closest state of the art which is not considered to be of particular relevance
  *E* earlier document but published on or after the international filing date
  *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
  *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

Date of the actual completion of the international search
8 November 2007

Date of mailing of the international search report
26/11/2007

Authorized officer
Gnugesser, Hermann
<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
</table>
INTERNATIONAL SEARCH REPORT

Box No. II  Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. □ Claims Nos.: 32, 33
   because they relate to subject matter not required to be searched by this Authority, namely:
   see FURTHER INFORMATION sheet PCT/ISA/210

2. □ Claims Nos.: because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. □ Claims Nos.: because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III  Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. □ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. □ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of additional fees.

3. □ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. □ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

□ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

□ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

□ No protest accompanied the payment of additional search fees.

Form PCT/ISA/210 (continuation of first sheet (2)) (April 2005)
Continuation of Box II.1

Claims Nos.: 32,33

Claims 32 and 33 explicitly refer back to the accompanying drawings contrary to Rule 6.2(a) PCT and PCT International Search and Examination Guidelines, Chapter 5 (claims), "General", "Form and Content of Claims", paragraph 5.10:

"The claims must not, in respect of the technical features of the invention, rely on references to the description or drawings "except where absolutely necessary." In particular, they must not normally rely on references such as: "as described in part ... of the description" or "as illustrated in Figure 2 of the drawings." The emphatic wording of the excepting clause should be noted. Thus, the applicant should be invited to show that it is "absolutely necessary" to rely on reference to the description or drawings in appropriate cases. An example of an exception would be that in which the invention as claimed involved some peculiar shape illustrated in the drawings but which could not be readily defined either in words or by a simple mathematical formula. Another special case is that in which the invention relates to chemical products whose features can be defined only by means of graphs or diagrams."

The above exceptions of the Guidelines do not meet the case of present claims 32 and 33.
## INTERNATIONAL SEARCH REPORT

<table>
<thead>
<tr>
<th>Patent document cited in search report</th>
<th>Publication date</th>
<th>Patent family member(s)</th>
<th>Publication date</th>
</tr>
</thead>
</table>