Title: WAVELENGTH REFERENCE DEVICE

Abstract: A wavelength reference device (110) for tuning a tunable Fabry-Perot filter and/or a tunable VCSEL (105) to a desired frequency, where the device uses a Fizeau interferometer (125) and a position sensitive detector (130), with the position sensitive detector (130) being used to measure the location of the maximum reflected power from the interferometer (125), whereby to determine the wavelength of laser radiation for tuning the device (110).
WAVELENGTH REFERENCE DEVICE

Reference To Pending Prior Patent Application

This patent application claims benefit of pending prior U.S. Provisional Patent Application Serial No. 60/150,246, filed 08/23/99 by Reich Watterson et al. for VCSEL INTEGRATED WITH WAVELENGTH REFERENCE, which patent application is hereby incorporated herein by reference.

Field Of The Invention

This invention relates to photonic devices in general, and more particularly to tunable filters and tunable lasers.

Background Of The Invention

In pending prior U.S. Patent Application Serial No. 09/105,399, filed 06/26/98 by Parviz Tayebati et al. for MICROELECTROMECHANICALLY TUNABLE, CONFOCAL, VERTICAL CAVITY SURFACE EMITTING LASER AND FABRY-PEROT FILTER, and in pending prior U.S. Patent Application
Serial No. 09/543,318, filed 04/05/00 by Peidong Wang et al. for SINGLE MODE OPERATION OF MICROMECHANICALLY TUNABLE, HALF-SYMMETRIC, VERTICAL CAVITY SURFACE EMITTING LASERS, which patent applications are hereby incorporated herein by reference, there are disclosed tunable Fabry-Perot filters and tunable vertical cavity surface emitting lasers (VCSEL’s).

More particularly, and looking now at Fig. 1, there is shown a tunable Fabry-Perot filter 5 formed in accordance with the aforementioned U.S. Patent Applications Serial Nos. 09/105,399 and 09/543,318. Filter 5 generally comprises a substrate 10, a bottom mirror 20 mounted to the top of substrate 10, a bottom electrode 15 mounted to the top of bottom mirror 20, a thin support 25 atop bottom electrode 15, a top electrode 30 fixed to the underside of thin support 25, a reinforcer 35 fixed to the outside perimeter of thin support 25, and a confocal top mirror 40 set atop thin support 25, with an air cavity 45 being formed between bottom mirror 20 and top mirror 40.
As a result of this construction, a Fabry-Perot filter is effectively created between top mirror 40 and bottom mirror 20. Furthermore, by applying an appropriate voltage across top electrode 30 and bottom electrode 15, the position of top mirror 40 can be changed relative to bottom mirror 20, whereby to change the length of the Fabry-Perot cavity, and hence tune Fabry-Perot filter 5.

Correspondingly, and looking next at Fig. 2, a tunable vertical cavity surface emitting laser (VCSEL) 50 can be constructed by positioning a gain medium 55 between bottom mirror 20 and bottom electrode 15. As a result, when gain medium 55 is appropriately stimulated, e.g., by optical pumping, lasing can be established within air cavity 45 and gain medium 55, between top mirror 40 and bottom mirror 20. Furthermore, by applying an appropriate voltage across top electrode 30 and bottom electrode 15, the position of top mirror 40 can be changed relative to bottom mirror 20, whereby to change the length of the laser's resonant cavity, and hence tune VCSEL 50.
Tunable Fabry-Perot filters and tunable VCSEL's of the type disclosed in the aforementioned U.S. Patent Applications Serial Nos. 09/105,399 and 09/543,318 are highly advantageous since they can be quickly and easily tuned by simply changing the voltage applied across the top electrode and the bottom electrode.

However, it has been found that tunable Fabry-Perot filters and tunable VCSEL's of the type disclosed in U.S. Patent Applications Serial Nos. 09/105,399 and 09/543,318 have performance characteristics which can vary slightly from unit to unit. In addition, it has also been found that the performance characteristics of any given unit can vary slightly in accordance with its age, temperature, etc. Accordingly, it is generally not possible to precisely predict in advance the exact voltage which must be applied to a particular device in order to tune that device to a specific frequency. This can present an issue in some applications, particularly
telecommunications applications, where the devices may need to be tuned to precise, absolute wavelengths.

Summary Of The Invention

As a result, one object of the present invention is to provide a novel wavelength reference apparatus for calibrating a tunable Fabry-Perot filter and/or a tunable VSCEL, whereby the device may be tuned to a precise, absolute wavelength.

Another object of the present invention is to provide a novel wavelength-locking apparatus for tuning a tunable Fabry-Perot filter and/or a tunable VCSEL to a precise, absolute wavelength, and for thereafter keeping that device tuned to that wavelength.

Still another object of the present invention is to provide a novel method for calibrating a tunable Fabry-Perot filter and/or a tunable VSCEL, whereby the device may be tuned to a precise, absolute wavelength.

Yet another object of the present invention is to provide a novel method for wavelength-locking a
tunable Fabry-Perot filter and/or a tunable VCSEL, whereby to tune the device to a precise, absolute wavelength, and for thereafter keeping that device tuned to that wavelength.

In one form of the invention, there is provided a wavelength reference apparatus for use in calibrating a device such as a tunable Fabry-Perot filter or a tunable VCSEL emitting laser radiation to a precise, absolute frequency, the wavelength reference apparatus comprising a collimation device for collimating a portion of the laser radiation, a Fizeau interferometer for receiving the collimated laser radiation, and a position sensitive detector for determining the position of maximum reflected power of the collimated laser radiation from the Fizeau interferometer.

In another form of the invention, there is provided a wavelength-locking apparatus for use in tuning a device such as a tunable Fabry-Perot filter or a tunable VCSEL emitting laser radiation to a precise, absolute frequency, the wavelength locking
apparatus comprising a collimation device for collimating a portion of the laser radiation, a Fizeau interferometer for receiving the collimated laser radiation, a position sensitive detector for determining the position of maximum reflected power of the collimated laser radiation from the Fizeau interferometer, and a controller for tuning the wavelength of the device by monitoring the position of maximum reflected power of the collimated laser radiation from the Fizeau interferometer on the position sensitive detector.

In yet another form of the invention, there is provided a method for tuning a device such as a tunable Fabry-Perot filter or a tunable VCSEL emitting laser radiation, comprising the steps of: (1) collimating laser radiation through a collimation device; (2) passing the collimated laser radiation into a Fizeau interferometer; (3) determining the position of maximum reflected power from the Fizeau interferometer; (4) identifying the frequency of the laser radiation according to the position of maximum
reflected power from the Fizeau interferometer; and
(5) using the position of the maximum reflected power
from the Fizeau interferometer to tune the device to
the desired frequency.

Brief Description Of The Drawings

These and other objects and features of the
present invention will be more fully disclosed or
rendered obvious by the following detailed description
of the preferred embodiments of the invention, which
is to be considered together with the accompanying
drawings wherein like numbers refer to like parts and
further wherein:

Fig. 1 is a schematic side view of a tunable
Fabry-Perot filter;

Fig. 2 is a schematic side view of a tunable
VCSEL;

Fig. 3 is a schematic diagram of wavelength
reference apparatus and wavelength-locking apparatus
for tuning a tunable Fabry-Perot filter and/or a
tunable VCSEL to a desired frequency, and for
thereafter keeping that device tuned to that frequency; and

Fig. 4 is a schematic diagram of wavelength reference apparatus formed in accordance with the present invention.

Detailed Description Of The Preferred Embodiments

Looking next at Fig. 3, there is shown a system 100 which provides a wavelength reference apparatus for calibrating a tunable Fabry-Perot filter and/or tunable VCSEL, whereby the device may be tuned to a precise, absolute wavelength. System 100 also provides a wavelength-locking apparatus to keep the tunable Fabry-Perot filter and/or tunable VCSEL tuned to a precise, absolute wavelength.

More particularly, system 100 generally comprises a tunable Fabry-Perot filter or tunable VCSEL 105, a wavelength reference apparatus 110, and a controller 115.

Tunable Fabry-Perot filter or tunable VCSEL 105 preferably comprises a tunable Fabry-Perot filter or
tunable VCSEL of the type disclosed in U.S. Patent Applications Serial Nos. 09/105,399 and 09/543,318. For convenience of description, tunable device 105 will hereinafter be described in the context of being a tunable VCSEL; however, it will be appreciated that the present invention is equally applicable to the situation where tunable device 105 comprises a tunable Fabry-Perot filter. Of course, using wavelength reference device 110 with a tunable Fabry-Perot filter would require that the tunable filter be illuminated by an external broad band light source (see Fig. 3). This broad band light source could be either optically combined with, or switched with, a normal incoming light signal.

In accordance with a preferred embodiment of the invention, and looking now at Fig. 4, wavelength reference device 110 comprises a collimation device 120, a Fizeau interferometer 125, and a position sensitive detector 130, as will hereinafter be discussed in further detail.
Controller 115 comprises circuitry for reading the output of detector 130 and adjusting the voltage applied to VCSEL 105 so as to tune VCSEL 105 to the desired wavelength, and to thereafter keep it tuned to that wavelength, as will hereinafter be discussed in further detail.

In essence, the tunable Fabry-Perot filter or tunable VCSEL 105 is used to sweep light through wavelength reference device 110 at monotonic wavelengths. This is done by either changing the frequency of the source (i.e., VCSEL 105) or by tuning a tunable optical filter inserted in the optical path. This light is passed through collimation device 120 and into Fizeau interferometer 125. In accordance with the function of a Fizeau interferometer, maximum reflected power will occur at different locations along the axis of the interferometer according to the wavelength of the light entering the interferometer. The position sensitive detector 130 is used to detect the position 135 of maximum reflected power, and hence the absolute wavelength, of the light entering the
interferometer. As a result, VCSEL 105 may be tuned to a desired target frequency.

Collimation device 120 is an optical element mounted adjacent to the emitting face of VCSEL 105. This optical element may be a ball lens or a gradient index (GRIN) lens. Collimation device 120 collimates a portion of the laser radiation emitted from VCSEL 105. The collimated laser radiation is then directed to Fizeau interferometer 125.

Fizeau interferometer 125 is preferably mounted within the same housing as VCSEL 105 and receives collimated laser radiation. Fizeau interferometer 125 includes a pair of plates 140, 145 set at an inclination with respect to one another. Plate 140 is set at an inclination with respect to the optical path of emitted radiation from collimation device 120. Plates 140, 145 have a partially reflective coating applied to the inner surfaces facing each other, and have an anti-reflective coating applied to the outer surfaces not facing each other. Collimated laser
radiation is reflected between plates 140, 145 and strikes position sensitive detector 130.

Position sensitive detector 130 is located adjacent to Fizeau interferometer 125. Detector 130 is used to determine the position of maximum reflected power along the long axis of plate 145. Detector 130 generates an electrical output based upon the position of the detected radiation.

To determine the wavelength of radiation exiting from the VCSEL, the electrical output of detector 130 is compared to reference electrical signals corresponding to known wavelengths. These reference electrical signals are determined by calibrating wavelength reference device 110 with known wavelengths of collimated radiation. Importantly, these reference electrical signals have a direct correspondence to wavelength which is not dependent on the temperature or age of the system.

An electrical feedback loop provides a signal from position sensitive detector 130 to controller 115. In turn, controller 115 adjusts the tuning
voltage applied to VCSEL 105 and hence the wavelength of laser radiation emitted by VCSEL 105.

By way of example but not limitation, suppose that at a given voltage $X$, VCSEL 105 is generating light with a frequency $Y$. At this point, the position sensitive detector 130 will detect the position 135 of maximum reflected power at the position which corresponds to the frequency $Y$. Suppose further that it is desired to tune VCSEL 105 so that it is generating light at a given ITU frequency. In this case, the voltage being applied to VCSEL 105 is adjusted until position sensitive detector 130 detects the position 135 of maximum reflected power at the position which corresponds to the desired target frequency, whereupon VCSEL 105 will be generating light at the desired ITU frequency. Correspondingly, if it is desired to tune VCSEL 105 to another ITU frequency, the voltage being applied to VCSEL 105 is adjusted until the position 135 of maximum reflected power is located at the position which corresponds to
the desired ITU frequency, whereupon VCSEL 105 will be generating light at the desired ITU frequency.

Furthermore, once VCSEL 105 has been tuned to the desired target frequency, the position 135 of maximum reflected power on position sensitive detector 130 can be monitored; if the position of maximum reflected power drifts off the desired location (i.e., indicating that VCSEL 105 has drifted off the desired target frequency), the system can adjust the voltage being applied to VCSEL 105 so as to bring the VCSEL back to the desired frequency by driving the output back to the desired wavelength.

As there is a direct correspondence between the position 135 of maximum reflected power and the absolute wavelength of the light being generated by VCSEL 105, temperature compensation is not necessary. Furthermore, by integrating wavelength reference device 110 with VCSEL 105, the system is also thermally stable since the wavelength reference is integral to the thermoelectric temperature control
device of VCSEL 105. Therefore, secondary temperature control is not required.

For the purposes of this invention, the detection of the location of maximum reflected power from Fizeau interferometer 125 as the wavelength of the input light is varied (either by direct tuning, i.e., of a tunable laser source, or by the use of a tunable optical filter) will correspond to the identification of the wavelength of the transmitted light.

Numerous advantages are achieved through the use of the present invention.

For one thing, an effective optical wavelength reference is provided in an extremely compact physical layout.

For another thing, an extremely compact VCSEL laser and a wavelength reference device are integrated into a single housing.

In addition, a simple electronics drive circuit is used, which uses the positioning of maximum reflection of laser radiation to determine frequencies.
Furthermore, effective temperature compensation is not necessary as a thermally stable wavelength reference device is provided.

It is to be understood that the present invention is by no means limited to the particular constructions and method steps disclosed above and/or shown in the drawings, but also comprises any modifications or equivalents within the scope of the claims.
What Is Claimed Is:

1. A wavelength reference apparatus for use in calibrating a device such as a tunable Fabry-Perot filter or a tunable VCSEL emitting laser radiation to a precise, absolute frequency, the wavelength reference apparatus comprising:
   - a collimation device for collimating a portion of the laser radiation;
   - a Fizeau interferometer for receiving the collimated laser radiation; and
   - a position sensitive detector for determining the position of maximum reflected power of the collimated laser radiation from the Fizeau interferometer.

2. A wavelength reference apparatus according to claim 1 wherein the Fizeau interferometer comprises first and second plates, the first and second plates each having a facing and non-facing side relative to said other plate, the facing sides having a partially reflective coating, the non-facing sides having an
anti-reflective coating, and the first plate being at an inclination to the collimated laser radiation.

3. A wavelength reference apparatus according to claim 1 wherein the position sensitive detector comprises at least one discrete sensitive area to determine the position of maximum reflected power of the collimated laser radiation from the Fizeau interferometer.

4. A wavelength-locking apparatus for use in tuning a device such as a tunable Fabry-Perot filter or a tunable VCSEL emitting laser radiation to a precise, absolute frequency, the wavelength locking apparatus comprising:

   a collimation device for collimating a portion of the laser radiation;

   a Fizeau interferometer for receiving the collimated laser radiation;
a position sensitive detector for determining the position of maximum reflected power of the collimated laser radiation from the Fizeau interferometer; and

a controller for tuning the wavelength of the device by monitoring the position of maximum reflected power on the position sensitive detector.

5. A wavelength-locking apparatus according to claim 4 wherein the Fizeau interferometer further comprises first and second plates, the first and second plates each having a facing and a non-facing side relative to said other plate, the facing sides having a partially reflective coating, the non-facing sides having an anti-reflective coating, and the first plate being at an inclination to the collimated laser radiation.

6. A wavelength-locking apparatus according to claim 4 wherein the position sensitive detector comprises at least one discrete sensitive area to determine the position of maximum reflected power of
the collimated laser radiation from the Fizeau interferometer.

7. A method for tuning a device such as a tunable Fabry-Perot filter or a tunable VCSEL emitting laser radiation, comprising the steps of:

(1) collimating laser radiation through a collimation device;

(2) passing the collimated laser radiation into a Fizeau interferometer;

(3) determining the position of maximum reflected power from the Fizeau interferometer;

(4) identifying the frequency of the laser radiation according to the position of maximum reflected power from the Fizeau interferometer; and

(5) using the position of the maximum reflected power from the Fizeau interferometer to tune the device to the desired frequency.
8. A system comprising:

a tunable filter for emitting laser radiation;

and

a wavelength-locking apparatus for use in tuning
the tunable filter to a precise, absolute frequency,
the wavelength locking apparatus comprising:

a collimation device for collimating a
portion of the laser radiation;

a Fizeau interferometer for receiving the
collimated laser radiation;

a position sensitive detector for
determining the position of maximum reflected power of
the collimated laser radiation from the Fizeau
interferometer; and

a controller for tuning the wavelength of
the filter by monitoring the position of maximum
reflected power on the position sensitive detector.

9. A system comprising:

a tunable VCSEL for emitting laser radiation; and
a wavelength-locking apparatus for use in tuning
the tunable VCSEL to a precise, absolute frequency,
the wavelength locking apparatus comprising:
    a collimation device for collimating a
portion of the laser radiation;
    a Fizeau interferometer for receiving the
collimated laser radiation;
    a position sensitive detector for
determining the position of maximum reflected power of
the collimated laser radiation from the Fizeau
interferometer; and
    a controller for tuning the wavelength of
the VCSEL by monitoring the position of maximum
reflected power on the position sensitive detector.
Integrated VCSEL Wavelength Reference

110

105

120

130

Emitting Radiation (Optical Path)
Collimation device (ball lens for example)
Position Sensitive Detector
Position of maximum reflection for a particular wavelength
Inclined Plate (Fizeau) Interferometer

145

140

135

FIG. 4
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) : G01B 9/02
US CL : 356/352, 454
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)
U.S. : 356/352, 454

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
NONE

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>
</table>

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

Date of the actual completion of the international search: 24 JANUARY 2001
Date of mailing of the international search report: 09 FEB 2001

Name and mailing address of the ISA/US Commissioner of Patents and Trademarks
Box PCT
Washington, D.C. 20231
Facsimile No. (703) 305-3230

Authorized officer
PHILIP NATIVIDAD
Telephone No. (703) 308-0956

Form PCT/ISA/210 (second sheet) (July 1998)