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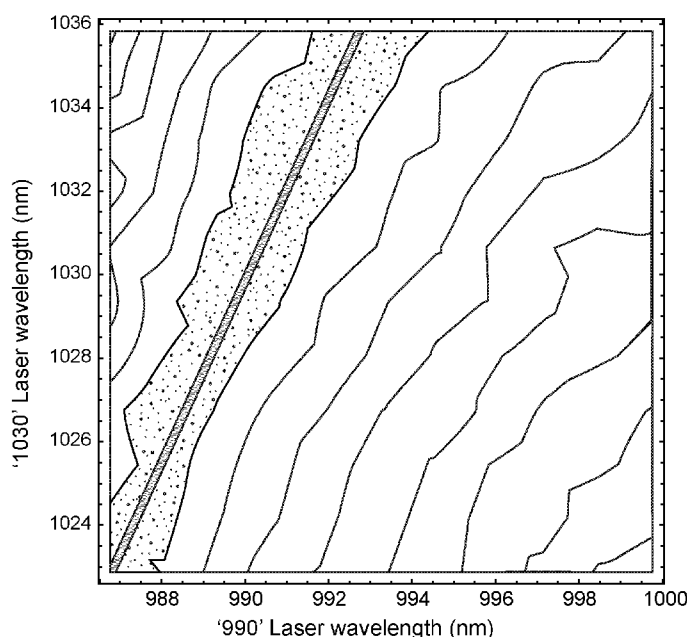


FIG. 2

(57) Abstract: A method is described for enabling Raman Based Distributed Temperature Sensing (DTS) systems to operate over larger environmental temperature ranges than any systems available today.



Title

Distributed Temperature Sensing over Extended Temperature Ranges

5

Background

The discovery reported below is the enablement of Raman based Distributed Temperature Sensing (DTS) systems that can operate over a larger environmental temperature range than the systems available today.

A single wavelength Raman based Distributed Temperature Sensing (DTS) system sends out a short laser pulse and measures back scattered Stokes and anti-Stokes light. The transmitted pulse as well as the back-scattered light passes through a number of optical components with different wavelength dependent attenuations as well as through the optical fiber where they experience wavelength dependent optical attenuation. This wavelength dependent optical attenuation causes differential attenuation between the Stokes and anti-Stokes intensities. The laser center wavelength is tuned using a thermo-electric cooler (TEC) to match the optical filters that are used to filter out the Stokes and anti-Stokes, i.e. each DTS system is tuned to a specific wavelength to get a known differential attenuation, and the remnant differential attenuation can then be compensated using e.g. a correction factor that is proportional to the travel distance along the optical fiber. If anything affects the measured Stokes and anti-Stokes intensities, e.g. optical fiber attenuation change over wavelength and/or distance, laser wavelength shift or optical component attenuation that is different between the Stokes and anti-Stokes optical path, then this will result in a false report of the measured temperature, i.e. measurement error. Each single wavelength DTS system is carefully tuned and calibrated around the set-point of the laser. The environmental range where a DTS system can

maintain its calibration is highly dependent on the temperature range where the thermo-electric cooler (TEC) can maintain temperature lock (and thus laser wavelength lock), typically up to +/-30C or even up to +/-40C. The same challenge holds true for another important opto-
5 electronic component in laser systems, i.e. the photo diode (Avalanche Photo Diode or APD) where the temperature is also TEC controlled.

A dual laser DTS requires careful tuning of each laser within the filter window as well as careful tuning of the wavelength separation between
10 the two lasers. A properly tuned dual laser system will not have measurement error due to changes in intensity between the Stokes and anti-Stokes components. In dual laser systems, we have to properly tune a system such that the effective Rayleigh attenuation of the laser at the Stokes wavelength is equivalent to the attenuation experienced by
15 the Anti-Stokes of the Raman backscattered light, and vice-versa.

Certain combinations of dual lasers have proven to be very effective in a number of applications in providing effective self-calibration or auto correction methodology. Some proven commercial systems include a
20 primary wavelength of 975 (nm) coupled with a correcting light source of 940 (nm). Another is a primary wavelength of 1500 (nm) coupled with a correcting light source of 1410 (nm). And a third would be a commercially available measurement light source of primary wavelength of 1030 (nm) coupled with a correcting light source of 990 (nm).

25

The methodology disclosed herein can be used in a number of these dual laser DTS systems. For illustrative purposes the third example given here – a commercially available measurement light source of primary wavelength of 1030 (nm) coupled with a correcting light source
30 of 990 (nm) will be used as an illustrative example throughout.

In another embodiment presented herein the application of this approach to single laser systems will be illustrated and a single laser of wavelength 990nm will be used to illustrate.

5 Due to the thermal sensitivity in the available lasers Thermoelectric coolers (TEC) are often employed to maintain the laser setpoint. Unfortunately, TECs, however useful, have several challenges that are relevant to this problem:

- 10 1) There is a maximum temperature delta that any TEC can maintain. TECs remove heat from one side of the TEC to another side of the TEC, and this heat must then be removed. This is in particular challenging in hot environments where there is a challenge to remove the heat from the hot side of the TEC.
- 15 Failure to remove this heat may result in thermal run-away of the TEC and catastrophic failure of the laser.
- 2) TECs require a fair amount of power to hold their temperature setpoint, and this power consumption increases exponentially as the temperature difference between the environment and the
- 20 setpoint increases. I.e. the efficiency of TEC's decrease as the environmental temperature move further away from the setpoint, and this cause a number of challenges.

The problem occurs when experiencing large temperature deltas. For

25 practical reasons, regions that experience large temperature deltas, i.e. > 40 C in a short time period, are often extremely remote and have severely tight restrictions when it comes to power draw. Most places are not connected to the power grid and systems must be run off of batteries, which can be recharged by a number of means, e.g.

30 mechanical, replacement, or solar. All power options turn out to be prohibitive in either cost, size or system/data reliability. Options to heat

or cool enclosures where the DTS is housed exist but they drive power consumption and overall system size, which in the end drives cost.

5 For large temperature deltas, the power requirements of the TEC will eclipse the power draw of every other component in the DTS system by a factor of two easily. Eventually once, the TEC maximum delta has been reached within the DTS system, the TEC temperature setpoint will drift. Once drifting begins, measurement errors are introduced. Functionally what this means is that data becomes unreliable and may
10 vary with environmental temperature. For long term production monitoring, where we are concerned with .5 K temperature deltas, this degradation in calibration accuracy will quickly become an issue.

In remote locations, stand-alone systems are required, and the system
15 cost is directly related to the power consumption. E.g. large solar powered systems require larger batteries and larger enclosures, and by forcing a TEC to run at its maximum, the power consumption will increase, and the system must be sized for the worst-case conditions.

20 There is then a need for a new approach, one that maintains system accuracy over the full extended temperature range expected while maintaining lower power requirements.

25

Brief Description of the Drawings

5 Figure 1 is a flow chart of the method for generating the map of Figure 2.

Figure 2 illustrates a temperature measurement error map for a dual laser DTS system as a function of incident wavelengths. It is generated using the method of Figure 1.

10

Figure 3 illustrates the power draw of a TEC as a function of temperature delta held.

Figure 4 illustrates a decision flow chart for determining which
15 wavelengths to use in dual laser systems.

Figure 5 is a flow chart of the method for generating the map of Figure 6.

Figure 6 illustrates a temperature measurement error map as a function
20 of incident wavelengths. It is generated using the method of Figure 1

Detailed Description

In the following detailed description, reference is made to accompanying
5 drawings that illustrate embodiments of the present disclosure. These
embodiments are described in sufficient detail to enable a person of
ordinary skill in the art to practice the disclosure without undue
experimentation. It should be understood, however, that the
embodiments and examples described herein are given by way of
10 illustration only, and not by way of limitation. Various substitutions,
modifications, additions, and rearrangements may be made without
departing from the spirit of the present disclosure. Therefore, the
description that follows is not to be taken in a limited sense, and the
scope of the present disclosure will be defined only by the final claims.

15

The traditional way to tune a DTS system is to define a setpoint and tune
the system to work +/-30C or maybe +/-40C around this setpoint. This
result in the challenges described earlier. Systems are now required that
can function from -40C (northern locations) to as high as 70C (desert
20 locations). This range far exceeds capability of TEC's employed.

Disclosed herein is a solution set where the setpoints can be dynamically
changed based on the environmental temperature to minimize the power
consumption of the laser TEC's while expanding the environmental
25 temperature operating range of the DTS systems.

For the dual laser system, the autocorrection that occurs depends on the
wavelengths of the transmitted laser pulses, the back-scattered Stokes
and anti-Stokes components and how they are located within the optical
30 bandwidth of the receiving optics. The receiving optics may have
temperature dependent attenuation that may vary with environmental
temperature. An optimized operating setpoint can then be identified for

any given sub-temperature range within the full environmental temperature range. A number of pre-defined operating setpoints with appropriate overlap can then be calibrated and a system may change set-point based on the environmental temperature. A DTS system is no longer dependent on the maximum swing of the laser TEC as traditionally used.

This means that a system calibration now becomes a dynamic calibration where the lasers are tuned while minimizing the power consumption of the TECs controlling the opto-electronic components such as lasers and APDs. Since semiconductor lasers have very well known wavelength dependence as a function of temperature (nominally .3 nm/C), the temperature setpoint of the lasers can be made in response to the ambient temperature of the DTS unit. In so doing, both the power draw of the unit and the induced temperature measurement error can be minimized.

The method to be described can be understood by simultaneously viewing Figures 1 and 2. Figure 2 illustrates a map where bands of induced measurement error vs. laser tuning wavelength for a dual laser system has been identified. Figure 1 is a flowchart of how Figure 2 is generated.

In a dual laser DTS system, this is how the differential attenuation in Figure 2 manifests. The goal then, is to pick a wavelength for the '990 nm' laser that falls on the straight line, then use the complimentary '1030 nm' wavelength. For example, picking 988 nm for the '990 nm' laser would require thermally setting the '1030 nm' laser to 1026 nm.

This map can be systematically produced scanning over the setpoint range of the thermoelectric controllers. When you take a trace of this

fiber (described below), the amount of error induced by differential attenuation will result in distance dependent temperature error which can be quantified as a slope, $\Delta(\text{degrees C})/\Delta(\text{distance in km})$.

5 The steps for taking such a trace are detailed in Figure 1 as follows:

First, in step **10** a DTS system is installed in an environmental chamber and connected to outside fiber spool held at constant measured temperature. The fiber spool can be made up of one or more optical
10 fibers with varying optical properties ranging from new pristine fibers to heavily Hydrogen darkened fibers. In a second step **20** we set the environmental chamber to the minimum of the full extended environmental temperature range expected. The first laser TEC is then set **30** at the minimum of the full extended temperature range expected.
15 The second laser is then set **32** at the minimum of the full extended temperature range expected. Then **34, 36** the second laser setpoints are stepped through a series of pre-determined increases until the second laser TEC maximum setpoint is reached. As this is done all of the laser wavelengths, temperatures measured with DTS, actual optical
20 fiber temperatures, and TEC power consumptions are recorded.

The first laser TEC setpoint is then increased by a predetermined amount and the process **32,34,36** for the second laser is repeated. As this process continues all laser wavelengths, DTS measured
25 temperatures, actual optical fiber temperatures and TEC power consumptions are recorded **34**.

Once the two lasers TEC's have been stepped through the expected temperature range the environmental chamber's temperature is
30 increased and the entire sequence **30,32,34,36,38** is repeated **40** until the full matrix is completed.

This process generates **50** the matrix of laser wavelengths of the first and second lasers of Figure 2. The solid line in that plot represents the minimum measurement error with minimum power consumption across the full extended environmental temperature range expected.

5

An optimized solution map will also include temperature induced component attenuation that may impact accuracy settings for other opto-electric components such as the photo detector(s).

10 In addition to accuracy, we have to keep in mind power draw. As can be seen in Figure 3, by doubling the temperature delta held, we quadruple the amount of power required to hold a setpoint. With this constraint we can identify a region of the parameter space that satisfies both requirements of low power draw and minimizing the impact on data
15 quality.

From Figure 2 the straight line corresponds to wavelength pairs needed for a correctly tuned DTS. Figure 2 demonstrates that there are several complimentary wavelength pairs that provide a properly tuned DTS.

20 With Figure 3 in mind, for an ambient temperature of 40 C, we would set the 990 nm laser to 988 nm, and the 1030 nm laser to 1026 nm. If the ambient temperature were to increase to 55 C though, we would then tune the 990 nm laser to 992 nm and the 1030 nm laser to 1032 nm to minimize the power draw of the system while making sure that the
25 temperature traces are accurate. This new setpoint would be good for an ambient up to 75 C without impacting power draw.

Figure 4 illustrates the decision tree for determining the wavelengths to use in a dual laser system. When the difference between the
30 Environmental Temperature and the Temperature of the laser TEC setpoints is too large compared to a predetermined threshold value of acceptable wavelengths, resulting in excess power consumption, the

laser setpoints are adjusted based on the dark line created from Figures 1 and 2. This is repeated until the power consumption is in an acceptable range.

5 **Single Laser systems**

Note that in DTS systems both temperature and wavelength dependent attenuation can affect performance. In dual laser systems with auto correction the design of the dual laser system and the wavelengths of
10 the two lasers chosen can effectively deal with the attenuation issue. For a single laser system however, we must make adjustments to account for attenuation. So for single laser systems we can generate a different map to use where the differential attenuation factor (DAF) is known as a function of incident wavelengths. As the incident wavelength
15 changes, so does the differential attenuation factor. The response of the detector may also vary with temperature, and may be tuned in sync with the laser setpoint. This can then be used to properly correct the data set for any changes due to changing DTS thermal operating setpoint for the opto-electric devices within the system.

20

The methodology for dealing with single laser DTS systems and applying DAF is illustrated in Figure 5, in a process similar to that of Figure 1 for dual laser systems.

25 First, in step **60** a DTS system is installed in an environmental chamber and connected to outside fiber spool held at constant measured temperature. As before the fiber spool can be made up of one or more optical fibers with varying optical properties ranging from new pristine fibers to heavily Hydrogen darkened fibers. In a second step **70** the
30 environmental chamber is set to the minimum of the full expected temperature range. The single laser TEC is then set **80** at the minimum of the full extended temperature range expected. Then **82** the DAF is

adjusted to obtain a flat temperature profile. Then **84** the laser wavelength, DAF, temperature measured with DTS, actual optical fiber temperature, and TEC power consumption of the laser TEC are recorded.

5

The single laser TEC setpoint is then increased by a predetermined amount and the process **82, 84, 86** is repeated, recording the laser wavelength, DAF, temperature measured with DTS, actual optical fiber temperature, and TEC power consumption of the laser TEC.

10

Once the single laser TEC's have been stepped through the full extended environmental temperature range expected the environmental chamber's temperature is increased by a pre-determined amount and the entire sequence **80, 82, 84, 86** is repeated until the full extended environmental temperature range expected is completed.

15

This process generates **100** a matrix of laser wavelengths of the single laser illustrated in Figure 6. The solid line in that plot represents the minimum measurement error with minimum power consumption across the full extended environmental temperature range expected.

20

Using the information of the recommended wavelength illustrated in Figure 6, when the difference between the Environmental Temperature and the Temperature of the laser TEC setpoints is too large, resulting in excess power consumption, the laser setpoint is adjusted based on the dark line created of Figure 6. This is repeated until the power consumption is in an acceptable range.

25

Incorporating APD TEC's into the Methodology

30

In another embodiment Avalanche Photo Diodes (APD's) with their associated TEC's are being used increasingly in long-range fiber optic

applications and represent another power draw in these systems. The methodology described herein could also be used to include the APD TEC's in the methodology for more power savings over extended temperature ranges. Referring to Figure 1 this can be done by adding
5 an additional step between steps **32** and **34** to set any APD TEC's setpoints to the minimum expected temperature, then add an additional loop within the **34,36** loop which stepwise increases the APD TEC setpoints over the full environmental temperature range expected, recording all of the data in step **34** and in addition recording the APD
10 TEC power consumptions. The process would still generate a final matrix of laser wavelengths that represent minimum measurement errors with minimum power consumption.

Stand-Alone Solar Power Systems Over Extended Environmental 15 Ranges

The methodology described herein is of great value in remote installations of DTS systems. Some example systems include cold climate areas in which oil and gas exploration is being done often require
20 permanent monitoring solutions utilizing fiber optics and associated electronics and these have several challenges from a logistics and/or environmental perspective. The available daylight may be low and the location normally doesn't have infrastructure so power must be supplied through batteries and solar panels. Temperature may dip very low in the
25 winter posing challenges for electronics and optics in terms of operating temperature. Heating the electronics is costly as the power system with batteries and solar panels grows and may not be practical. It is therefore desirable to have a more efficient system that minimizes the solar panels, batteries and environmental footprint, including mechanical,
30 environmental and visual.

The methodology described herein is illustrated by way of graphical representation as in Figures 2 and 6 but the matrix of recorded laser wavelengths, DAF, DTS temperature measurements, actual fiber temperatures, and various TEC power consumptions can be reduced to
5 hardware or software algorithms or look-up tables that are programmed to automatically minimize the power draw based on the environmental temperature in the field. Use of this methodology thus reduces the power draw and capital investment of batteries and solar panels needed over multiple systems in large fields. These multiple installations can
10 also be supplied with control units transmitting control signals to the DTS systems and communications units that receive commands from the control units and transmit the resultant data to data gathering stations.

Value Added

15 Earlier attempts include costly AC cooled enclosures and large solar panels whereas the proposed solution reduces the power footprint and associated cost while extending the environmental operating range. There is great need for extremely low power and accurate DTS systems.
20 Without properly calibrated systems data becomes unreliable, or power draw becomes too much to sustain in remote locations, or becomes cost prohibitive. The proposed solution makes it more possible to manufacture one set of DTS hardware for different applications and thereby reduce manufacturing cost and simplicity.

25 Although certain embodiments and their advantages have been described herein in detail, it should be understood that various changes, substitutions and alterations could be made without departing from the coverage as defined by the appended claims. Moreover, the potential
30 applications of the disclosed techniques is not intended to be limited to the particular embodiments of the processes, machines, manufactures, means, methods and steps described herein. As a person of ordinary

skill in the art will readily appreciate from this disclosure, other processes, machines, manufactures, means, methods, or steps, presently existing or later to be developed that perform substantially the same function or achieve substantially the same result as the

5 corresponding embodiments described herein may be utilized. Accordingly, the appended claims are intended to include within their scope such processes, machines, manufactures, means, methods or steps.

Claims

1. A method for choosing laser thermo-electric cooler (TEC)
5 temperature setpoints in distributed temperature sensing (DTS)
systems using first and second lasers with their associated
thermo-electric coolers (TECs) over extended environmental
temperature ranges comprising:
- 10 a. installing a dual laser distributed temperature sensing
(DTS) system in an environmental chamber connected to
an outside fiber spool held at a constant measured
temperature;
- b. setting the environmental chamber temperature to a
15 minimum of the full extended environmental temperature
range expected;
- c. then setting a first laser (TEC) setpoint to a minimum of the
full extended environmental temperature range expected;
- d. then setting a second laser (TEC) setpoint to a minimum of
20 the full extended environmental temperature range
expected;
- e. then stepping the second laser TEC setpoint in
predetermined steps across the full extended
environmental temperature range expected;
- f. and for each step (e.) recording laser wavelengths, DTS
25 temperature measurements, actual fiber temperature, and
TEC power consumptions for all TECs;
- g. then stepping the first laser TEC setpoint in predetermined
steps across the full extended environmental temperature
range expected, and for each first laser setpoint change
30 repeating steps (e.) and (f.);

- 5 h. then stepping the environmental chamber temperature in
predetermined steps across the full extended
environmental temperature range expected;
- i. then repeating steps (c-g) until a full matrix of data is
recorded; and
- j. then generating a matrix of first laser wavelengths versus
second laser wavelengths exhibiting the minimum
measurement error with minimum consumption across the
full extended environmental temperature range expected.
- 10
2. A method for determining the wavelengths for use in a dual laser
DTS system operating at a particular temperature over an
extended expected temperature range using the information
developed in claim 1 comprising:
- 15 a. determining the current environmental temperature;
- b. calculating the difference between the current
environmental temperature and the temperature of the TEC
setpoints;
- c. using the information generated from the method of claim 1
20 to determine if the TEC power consumption is within a
predetermined threshold value;
- d. and if the TEC power consumption is not within a
predetermined threshold value, then adjusting the laser
TEC setpoints from the information generated in claim 1 so
25 that the laser wavelengths are within a predetermined
threshold value;
- e. and the TEC power consumption is within a predetermined
threshold value, then proceed to measure the distributed
temperature using the adjusted laser wavelengths.
- 30
3. A method for choosing laser TEC and APD TEC setpoints in
distributed temperature sensing (DTS) systems using first and

second lasers with their associated thermo-electric coolers (TECs) over extended environmental temperature ranges comprising:

- 5 a. installing a dual laser distributed temperature sensing (DTS) system in an environmental chamber connected to an outside fiber spool held at a constant measured temperature;
- 10 b. setting the environmental chamber temperature to a minimum of the full extended environmental temperature range expected, then setting a first laser (TEC) setpoint to a minimum of the expected temperature range;
- c. then setting a second laser (TEC) setpoint to a minimum of the full extended environmental temperature range expected;
- 15 d. then setting APD TEC setpoints to a minimum of the full expected environmental temperature range expected;
- e. then stepping the APD TEC setpoints in predetermined steps across the full extended environmental temperature range expected;
- 20 f. and for each step (f.) recording laser wavelengths, DTS temperature measurements, actual fiber temperature, and TEC power consumptions for all TECs;
- g. then stepping the second laser TEC setpoint in predetermined steps across the full extended environmental temperature range expected, and for each second laser setpoint change repeating steps (e.) and (f.);
- 25 h. then stepping the first laser TEC setpoint in predetermined steps across the full extended environmental temperature range expected, and for each first laser setpoint change repeating steps (c thru h);
- 30

- i. then stepping the environmental chamber in predetermined steps across the full extended environmental temperature range expected;
 - j. then repeating steps (c-j) until a full matrix of data is recorded; and
 - k. then generating a matrix of first laser wavelengths versus second laser wavelengths exhibiting the minimum measurement error with minimum consumption across the full extended environmental temperature range expected.
4. A method for choosing laser thermo-electric cooler (TEC) temperature setpoints in distributed temperature sensing (DTS) systems using a single laser with its associated thermo-electric cooler (TEC) over extended environmental temperature ranges comprising:
- a. installing a single laser distributed temperature sensing (DTS) system in an environmental chamber connected to an outside fiber spool held at constant and accurately measured temperature;
 - b. setting the environmental chamber temperature to a minimum of the full extended environmental temperature range expected;
 - c. then setting the single laser TEC setpoint to a minimum of the full extended environmental temperature range expected;
 - d. then adjusting the differential attenuation factor (DAF) to obtain a flat temperature trace;
 - e. then stepping the single laser TEC setpoint in predetermined steps across the full extended environmental temperature range expected, repeating step (d.) each time;

- f. and for each step (e.) recording laser wavelength, DAF, DTS temperature measurements, actual fiber temperature, and TEC power consumptions for all TECs;
 - g. then stepping the environmental chamber temperature in predetermined steps across the full extended environmental temperature range expected;
 - h. then repeating steps (c-g) until a full matrix of data is recorded; and
 - i. then generating a matrix of first laser wavelengths versus second laser wavelengths exhibiting the minimum measurement error with minimum consumption across the full extended environmental temperature range expected.
- 5. A method for determining the wavelengths for use in a single laser DTS system operating at a particular temperature over an extended expected temperature range using the information developed in claim 4 comprising:
 - a. determining the current environmental temperature;
 - b. calculating the difference between the current environmental temperature and the temperature of the TEC setpoint;
 - c. using the information generated from the method of claim 4 to determine if the TEC power consumption is within a predetermined threshold value;
 - d. if the TEC power consumption is not within a predetermined threshold value, then adjusting the laser TEC setpoint from the information generated in claim 4 so that the laser wavelength is within a predetermined threshold value; and
 - e. if the TEC power consumption is within a predetermined threshold value, then proceed to measure the distributed temperature using the adjusted laser wavelength.

- 5 6. A system for improving the cost and efficiency of stand-alone fiber optic monitoring systems utilizing solar panels, batteries, and a dual laser DTS system with associated electronics for operating in extended environmental temperature ranges comprising:
- a. one or more stand-alone DTS systems utilizing dual lasers and associated electronics;
 - 10 b. one or more solar panel positioned above ground oriented toward incoming sunlight for providing power to the one or more DTS systems;
 - c. one or more battery systems for storing excess power from the one or more solar panels and powering the one or more DTS systems during inactive periods of the at least one solar panel;
 - 15 d. a control unit for controlling the one or more DTS systems;
 - e. one or more communications units to receive commands from the control unit and externally transmit data collected by the one or more DTS systems;
 - 20 f. wherein the laser wavelengths determined by the method of claim 2 are used in the one or more stand-alone DTS systems.
- 25 7. A system for improving the cost and efficiency of stand-alone fiber optic monitoring systems utilizing solar panels, batteries, and a single laser DTS system with associated electronics for operating in extended environmental temperature ranges comprising:
- a. one or more stand-alone DTS systems utilizing single lasers and associated electronics;
 - 30 b. one or more solar panel positioned above ground oriented toward incoming sunlight for providing power to the one or more DTS systems;

- c. one or more battery systems for storing excess power from the one or more solar panels and powering the one or more DTS systems during inactive periods of the at least one solar panel;
- 5 d. a control unit for controlling the one or more DTS systems.;
- e. one or more communications units to receive commands from the control unit and externally transmit data collected by the one or more DTS systems;
- 10 f. wherein a laser wavelength determined by the method of claim 5 are used in the one or more stand-alone DTS systems.

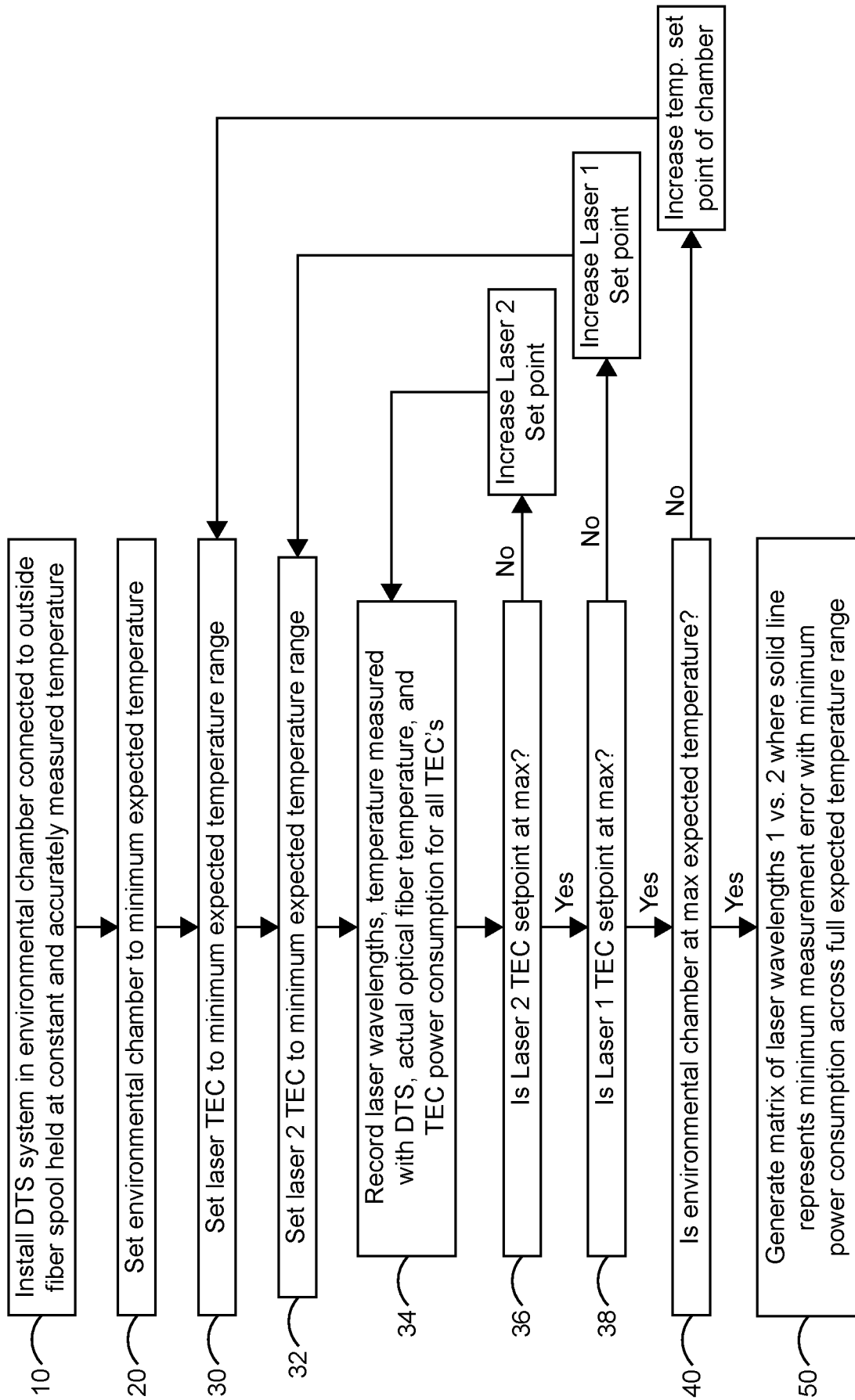


FIG. 1

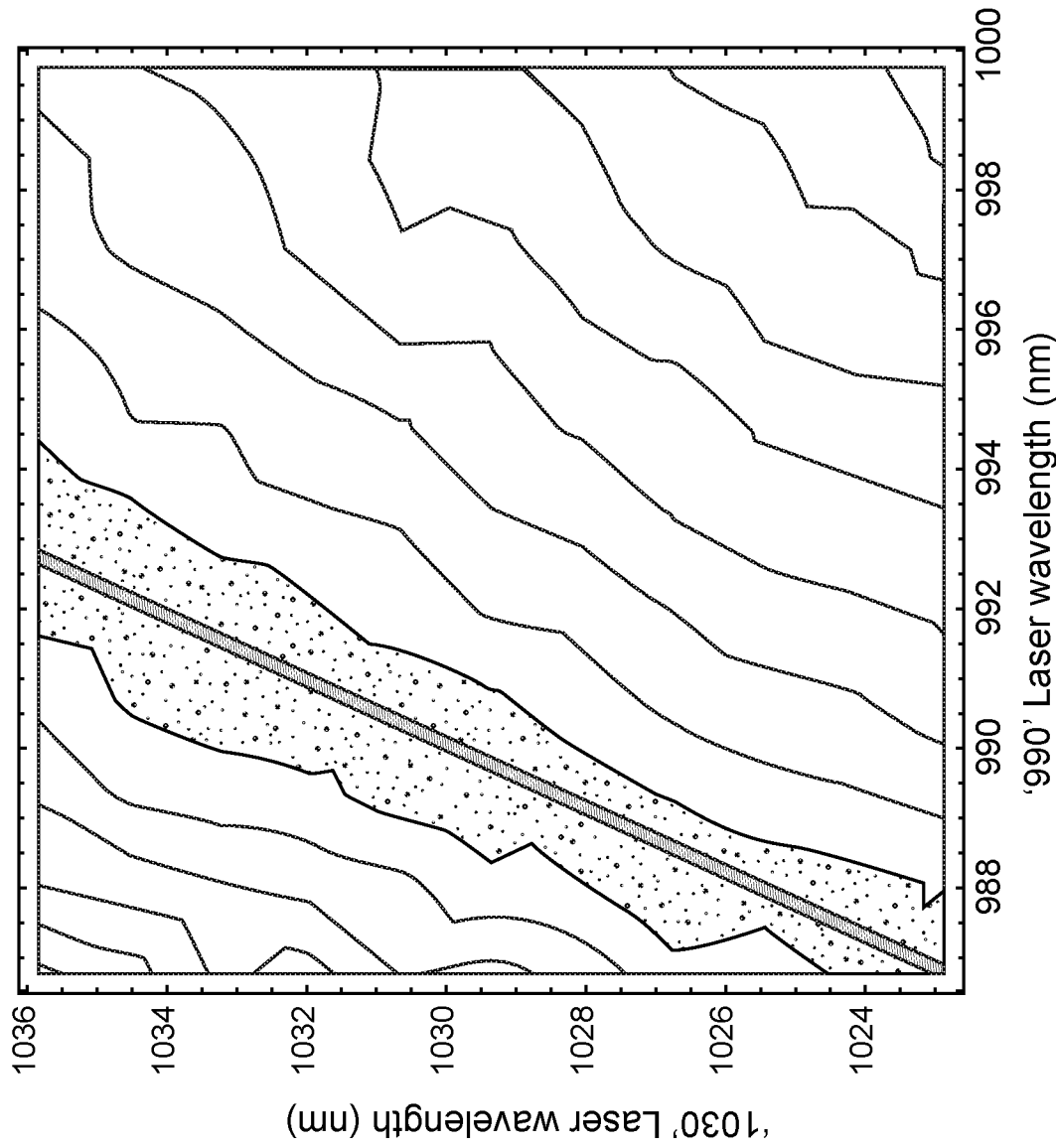


FIG. 2

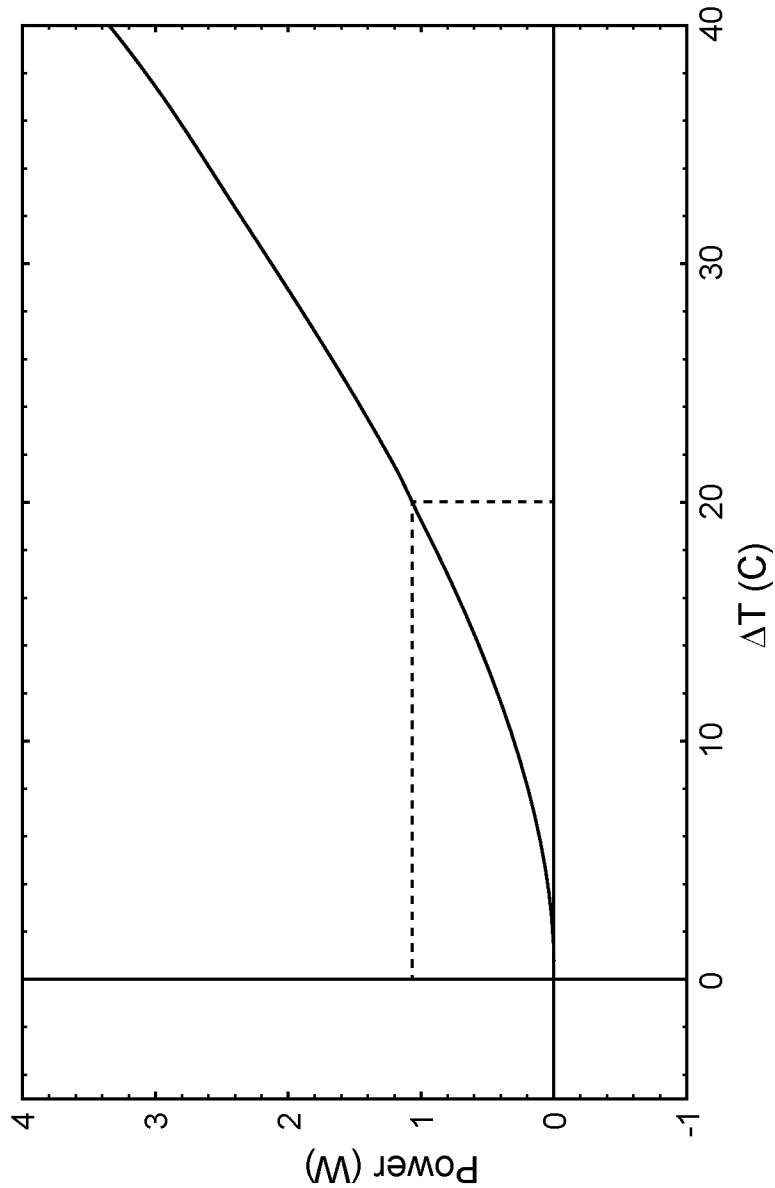


FIG. 3

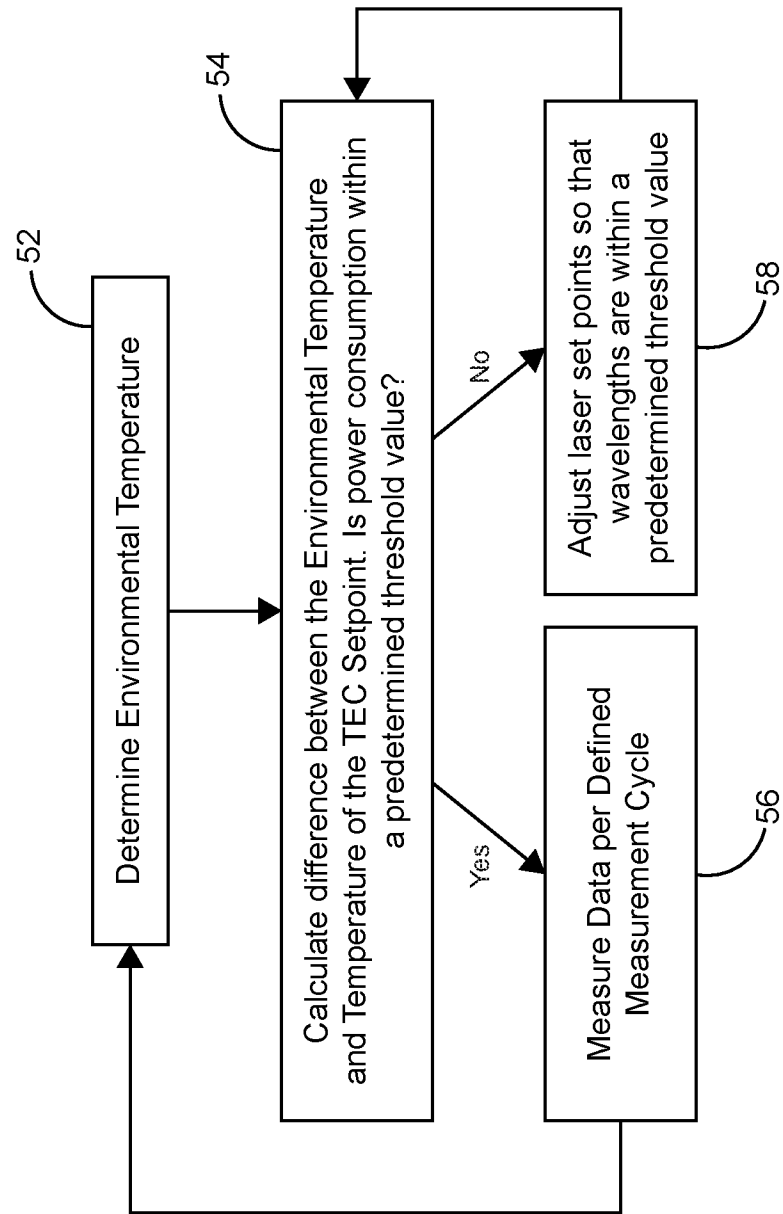


FIG. 4

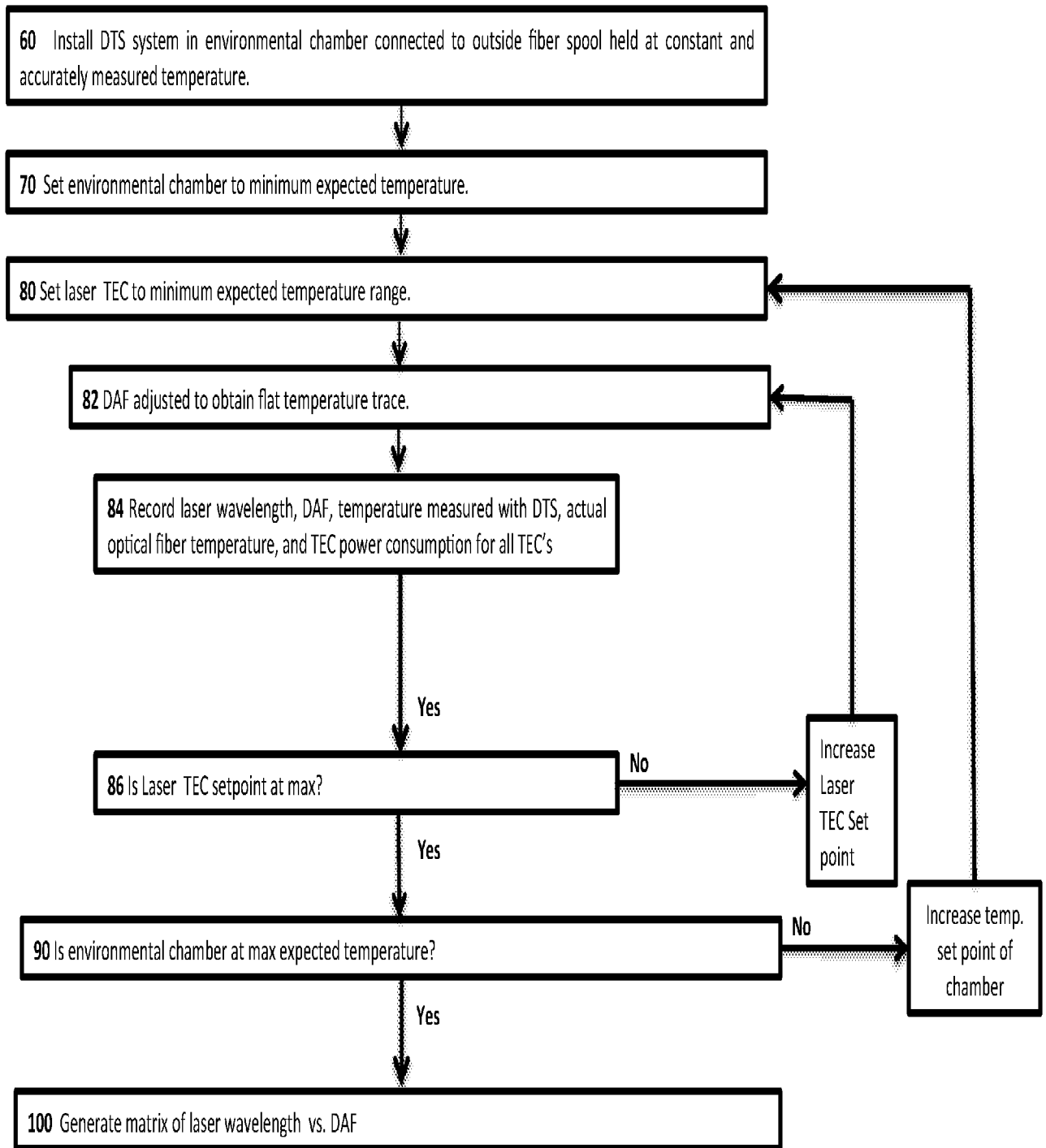


FIG. 5

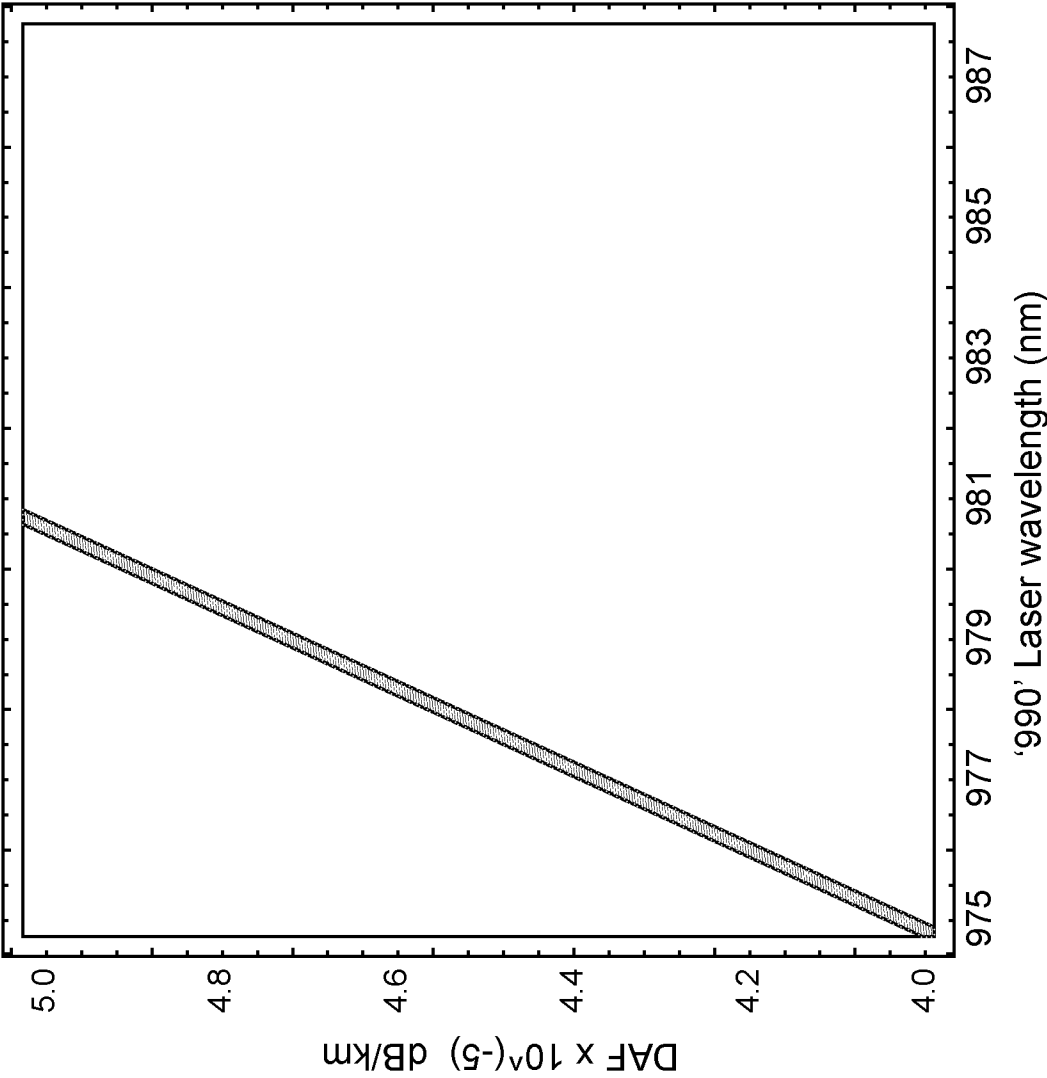


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/054393**A. CLASSIFICATION OF SUBJECT MATTER****G01K 11/32(2006.01)i**

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)

G01K 11/32; G01N 25/72; F25B 21/02; H04J 14/02; G01N 31/00; G01F 23/22

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & keywords: DTS, TEC, range, fiber, optic, solar panel, laser, battery, temperature and minimum

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6094918 A (BURBIDGE et al.) 01 August 2000 See abstract, claims 1-7 and figure 2.	1-7
A	US 2013-0215926 A1 (BELLI et al.) 22 August 2013 See abstract, paragraphs [0049]-[0055], claims 31-39 and figures 1-6B.	1-7
A	WO 2015-187922 A2 (APPLIED OPTOELECTRONICS, INC.) 10 December 2015 See abstract, claims 1-10 and figures 1-3.	1-7
A	WO 01-48471 A2 (CEYX TECHNOLOGIES) 05 July 2001 See abstract, claims 42-46 and figures 1a-4.	1-7
A	WO 2004-097348 A1 (SENSOR HIGHWAY LIMITED) 11 November 2004 See abstract, claims 17-25 and figures 1A-6.	1-7



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

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"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

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2016/054393

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 6094918 A	01/08/2000	None	
US 2013-0215926 A1	22/08/2013	US 9574949 B2	21/02/2027
WO 2015-187922 A2	10/12/2015	US 2016-0377822 A1 WO 2015-187922 A3	29/12/2016 14/01/2016
WO 01-48471 A2	05/07/2001	AU 2001-594601 A EP 1350096 A2 EP 1350096 B1 US 6494370 B1 WO 01-048471 A3	09/07/2001 08/10/2003 22/06/2011 17/12/2002 17/07/2003
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