An inexpensive, lightweight fiber optic micro-sensor that is suitable for applications which may require remote temperature sensing. The disclosed temperature sensor includes a phosphor material that, after receiving incident light stimulation, is adapted to emit phosphorescent radiation output signals, the amplitude decay rate and wavelength of which are functions of the sensed temperature.
**FIG. 3a**

**FIG. 3b**

**FIG. 3c**

**FIG. 3d**

**FIG. 3e**

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**FIG. 4**

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**FIG. 5**
FIBER OPTIC TEMPERATURE SENSOR

The invention described herein was made in the performance of work under NASA Contract No. NAS3-21005 and is subject to the provisions of section 305 of the National Aeronautics and Space Act of 1958 (72 Stat. 435; 42 U.S.C. 2457).

BACKGROUND OF THE INVENTION

1. Field of the Invention
The invention relates to a fiber optic microsensor that is suitable for remote temperature sensing applications.

2. State of the Prior Art
As is known to those skilled in the art, many temperature sensors are limited in application, because of their relatively large size and slow response time. Moreover, either complex transmission lines or signal conversion apparatus is typically required when the sample from which temperature information is collected is remotely positioned from the sensor body.

A fiber optic temperature sensor would otherwise be characterized as being inexpensive to manufacture, light in weight, capable of carrying wide bandwidth signals and immune to electromagnetic and electrostatic interference relative to conventional temperature sensors.

Examples of patents which disclose the combination of fiber optic apparatus and a phosphor material are as follows:

However, neither of the above recited patents shows or describes, it is to be understood that this is for illustrative purposes only. The first end of rod 4 is inserted into the sample 2, the temperature of which is to be monitored. Ultra-violet light, is transmitted from the source thereof to excite the phosphor particles 8 that are embedded in the fused sphere 6 of optical rod 4. The ultra-violet light causes the phosphor to luminesce. Phosphorescence is the luminescence which occurs shortly after (e.g. within 10 nanoseconds) the termination of the incident exciting light supply. The phosphor particles 8 emit output phosphorescent radiation that is characterized by a particular wavelength or color and an amplitude decay rate which are functions of the temperature encountered by the sphere 6. The output radiation may be transmitted from the phosphor particles 8 to a light detector (not shown) that is positioned adjacent the second end of the

SUMMARY OF THE INVENTION

Briefly, and in general terms, a pulse-width modulated luminescent fiber optic temperature sensor is disclosed. One end of a first elongated and flexible fiber optic rod is positioned in proximity to a light source to receive incident light therefrom. The second end of the first optical rod contains a supply of phosphor particles that are functions of the temperature encountered by the sphere 6. By way of example, the photoluminescent material 8 contains phosphor particles. Various types of phosphors may be utilized herein, depending upon the anticipated temperature range to which the sample will be exposed. A suitable light source 10, such as an ultra-violet supply, is positioned adjacent the second end of the optical rod 4 so as to apply incident light thereto.

In operation, the spherical end 6 of the fiber optic temperature sensor 1 is inserted into the sample 2, the temperature of which is to be monitored. Ultra-violet light is transmitted from the source thereof to excite the phosphor particles 8 that are embedded in the fused sphere 6 of optical rod 4. The ultra-violet light causes the phosphor to luminesce. Phosphorescence is the luminescence which occurs shortly after (e.g. within 10 nanoseconds) the termination of the incident exciting light supply. The phosphor particles 8 emit output phosphorescent radiation that is characterized by a particular wavelength or color and an amplitude decay rate which are functions of the temperature encountered by the sphere 6. The output radiation may be transmitted from the phosphor particles 8 to a light detector (not shown) that is positioned adjacent the second end of the
A fiber optic phosphorescence sensor is disclosed. In this embodiment the sensor includes a light emitting diode or a pulsed/continuous source. The light is transmitted via a fiber optic rod to a phosphor coated sphere. Light which is emitted from the phosphor is transmitted via a second fiber optic rod to a detector which converts the signal to electrical form. The output of the detector is amplified and/or compared to a reference level. A feedback loop is provided to the input of the amplifier. The temperature of the sphere is sensed by the phosphorescence output and is used to adjust the gain of the amplifier. The output of the amplifier is then passed to a sample/hold network which is used to supply a constant level to the input of the amplifier. The sample/hold network is activated during a first interval of time when radiation is incident on the sensor. During a succeeding interval of time the sample/hold network is de-activated so that the output signal level of the amplifier is used to control the gain of the amplifier. The output signal of the amplifier then serves as a real-time temperature sensor. It is to be understood that the number of fiber optic rods and detector may be varied as desired.
form (FIG. 3d or 3e) from the amplitude regulating system 38 at the end of the SAMPLE time interval initially has the amplitude L0, regardless of the maximum amplitude of the output signal (FIG. 3b or 3e) from photodetector 36, which amplitude may be affected by the attenuation of the output phosphorescent radiation signal that is transmitted from the coated sphere 28 to the output photodetector 36 via coupler 34 and optical fiber 32.

During that period of time after the termination of the SAMPLE interval, the time that is required for the intensity of the regulating system output signal to decay between two reference amplitudes, conveniently designated L1 and L2 in FIGS. 3d and 3e, is measured by a pulse width detector 44, such as a controlled counter. A physical characteristic of the phosphor 30 that is indicative of temperature is the variation in the rate of decay of the phosphorescent radiation output signal as a function of temperature. Therefore, pulse width detector 44 is connected to the output of variable gain amplifier 40 in order to measure the pulse width corresponding to the decay rate of the output signals from regulating system 38. Since the amplitude of the output signals from amplifier 40 are initially standardized at the level L0 regardless of temperature, the pulse width corresponding to the difference between any two suitable reference amplitudes such as, for example, between L0 and L2 could also be measured. More particularly, as shown in FIG. 3d, amplifier 40 provides an output wave form having a pulse width designated t1 which pulse width corresponds to the respective decay rate between levels L1 and L2 when sphere 28 is exposed to a sample having a first temperature. As shown in FIG. 3e, amplifier 40 provides an output wave form having a longer pulse width designated t2, which pulse width corresponds to the respective decay rate between reference levels L1 and L2 when sphere 28 is exposed to a sample having a second temperature.

It is to be recognized that the temperature sensor 20 which forms the present embodiment is operable in a pulse width modulated system, although the output pulse wave form (FIG. 3d or 3e) does not have a sharp square pulse, as is otherwise expected in a true pulse width modulated system. However, as has been previously pointed out, if either the amplitude of the electrical output signal (FIG. 3b or 3e) from the photodetector 36 or the attenuation of the phosphorescent output signal in optical rod 32 should change, the amplitude regulating system 38 will compensate for the effects thereof.

FIG. 4 of the drawings shows the phosphorescent decay characteristics of a selected luminescent phosphor material that has been excited by an incandescent lamp having wavelengths of 4500 Å, 3650 Å and 2537 Å. Such decay characteristics are explained in greater detail by H. W. Leverenz, An Introduction to Luminescence in Solids, John Wiley and Sons, New York, 1950. Examples are provided of the wide variation of output phosphorescent radiation decay rates which result from changing temperature. More particularly, the solid curves in FIG. 4 represent phosphor excitation from a 4500 Å lamp. The decay rates that are obtained correspond to the temperatures of 169° C., 313° C., and 404° C. At 169° C., the intensity of the phosphorescent radiation output signal decays by approximately 20% in a relatively short time interval (e.g. 0.1 seconds or less). At a temperature of 313° C., the intensity of the phosphorescent radiation output signal decays by approximately 10% in one second. Although the particular phosphor employed by the sensor at this last mentioned temperature has a relatively long decay rate, numerous other well known phosphors are available with shorter decay rates and quicker response times that are suitable for utilization herein.

As is also indicated in FIG. 4, the amplitude decay rate is a function of the wave length of the input exciting radiation. Moreover, the initial amplitude L0 of the output phosphorescent signal varies with temperature and the wave length of the incident light source, when compared to the initial amplitude L0 of the output radiation at 25° C. However, as disclosed above, the automatic gain control provided by the signal amplitude regulating system 38 of FIG. 2 automatically compensates for any variation in the initial light intensity L0 of the output phosphorescent radiation.

Another physical characteristic of a phosphorescent material that is indicative of temperature is the shift in wavelength or color of the output phosphorescent radiation that is emitted from the phosphor coating 30 as a function of temperature. In another embodiment of the present invention, FIG. 5 shows a portion of the temperature sensor 20 of FIG. 2 modified so as to be responsive to the color or wavelength of the output phosphorescent radiation. In the present embodiment, pulsed incident excitation is not required for the purpose of initiating transients for pulse width modulation (such as that described while referring to FIG. 2). Nevertheless, pulsed incident excitation may also be utilized in the temperature sensor 20 of FIG. 5 in order to avoid the crosstalk of the incident light signal with the phosphorescent radiation output signal in the coupler 34. Alternatively, however, the pulsed incident and radiation output signals can be separated by establishing a wide frequency or wavelength separation between the exciting illumination and the phosphorescent illumination. In this case, the system would be a wavelength modulated fluorescent detector rather than a pulse-width-modulated phosphorescent detector, as hereinbefore disclosed.

The structure of the fiber optic temperature sensor 20 illustrated in FIG. 5 is identical, in part, to that illustrated in FIG. 2 except that apparatus (e.g. a prism 46) is included to analyze the wavelength pattern of the output optical signal that is transmitted from the phosphor coated sphere (not shown) via coupler 34 and optical rod 32. In the present embodiment, the prism 46 is aligned between the end of optical rod 32 and a photodetector 48 so that the output optical signal is refracted and dispersed to form a display of colors. By way of example, photodetector 48 may include a well known linear array of charge coupled device cells, or the like. The photodetector 48 produces output electrical signals, which signals are representative of the changing temperature encountered by the phosphor coated sphere.

It will be apparent that while a preferred embodiment of the invention has been shown and described, various modifications and changes may be made without departing from the true spirit and scope of the invention. For example, although phosphor particles are either embedded in or coated on a fused sphere that is formed at the sensing end of the temperature sensors illustrated in FIGS. 1 and 2, respectively, it is to be understood that a light transmissive fiber optic rod may also be truncated to form a cleavage plane at the sensing end thereof. Hence, the phosphor particles could be embedded in or coated on the planar surface of the truncated sphere.
end of the optical rod that forms a temperature sensor disclosed herein. The illustrated fused sphere that is attached to the sensing end of a light transmissive optical rod is advantageous for maximizing thermal coupling between the temperature sensor and a sample to be monitored.

Having thus set forth a preferred embodiment of the present invention, what is claimed is:

1. A pulse-width-modulated temperature sensor comprising:
   a source of light pulses,
   a first optical fiber, one end of said first optical fiber being positioned in proximity to said source of light pulses to receive light pulses therefrom,
   a supply of photoluminescent material which has an emission amplitude decay rate which is a function of a temperature to be sensed to which said phosphor is exposed, said phosphor being located in proximity to another end of said first optical fiber to receive light therefrom,
   photodetector means, a second optical fiber, one end of said second optical fiber being positioned to receive light from said photoluminescent material and another end of said second optical fiber being positioned to deliver light to said photodetector means, thereby to conduct output phosphorescent emission signals thereto,
   signal amplitude regulating means connected to an output terminal of said photodetector means to receive therefrom electrical signal representations of the output phosphorescent emission signals and to adjust an initial amplitude thereof to a common signal level, and
   pulse width detector means connected to an output terminal of said signal amplitude regulating means, said pulse width detector being connected to measure the width of the amplitude adjusted signal representations of the output emission signals, whereby the width of said adjusted signal representations is indicative of the temperature to be sensed.

2. A temperature sensor comprising:
   an optical fiber, a light source positioned in light supplying relationship to one end of said optical fiber, a photoluminescent material in light receiving relationship to another end of said optical fiber, said photoluminescent material being of the type having a luminescence when excited by light supplied thereto from said light source, said luminescence providing an indication of a temperature to be sensed, photodetector means responsive to the luminescence of said photoluminescent material, and signal amplitude regulating means connected to an output terminal of said photodetector means to receive therefrom electrical signal representations of the luminescence and to initialize the amplitudes of said electrical signal representations to a common signal level.

3. The temperature sensor of claim 2, wherein said signal amplitude regulating means includes:
   a variable gain amplifier to receive from said photodetector means the electrical signal representations of the luminescence, and
   means to control the gain of said amplifier, whereby the amplitudes of the representations of said luminescence are initialized to the common signal level.

4. The temperature sensor recited in claim 3, further including a pulse width detector connected to an output terminal of said variable gain amplifier for measuring the width of the amplitude initialized electrical signal representations of said luminescence, whereby the width of said electrical signal representations is indicative of the temperature to be sensed.

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