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UVC RADIATION ON THE EARTH SURFACE AND WILDFIRES DETECTION

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Abstract: *An optical detection method for detecting wildfires at long distances is preferable so that the detector does not have to rely on smoke, heat or other indicators of fire. While fires emit light in the visible spectrum, most of the emitted radiation is in the infrared portion of the electromagnetic spectrum. Consequently, many fire detection systems rely on the detection of infrared radiation. However, various other warm or hot objects, such as the sun or its reflections, also emit large quantities of infrared radiation. Therefore, the infrared radiation sources must be distinguished spatially, and an array-type detector with an imaging and/or scanning system is often used for this purpose. Since the signal processing for such an array-type infrared detector is complex, these systems are generally expensive. Furthermore, these infrared detection systems are ineffective in detecting electrical arcs, which have low infrared emissions. Also, although some bands of the infrared spectrum (such as the 2.7 µm, 4.3 µm and 6.5 µm bands) are "solar blind" to some extent because the atmosphere blocks sunlight at those wavelengths and thereby prevents these solar wavelengths from reaching the ground, the usefulness of these infrared detectors in long-distance wildfire detection is limited since the atmosphere also blocks these wavelengths when they are emitted by a fire.*

Introduction

As more residences are built in forested parts of a country, the danger of wildfire becomes ever more ominous due to the number of lives and properties that are at risk. Particularly in dry or windy times and locations, a wildfire can double in size every few minutes. Without early detection, such a fire can quickly overwhelm any resources available to fight the fire. Early detection by a homeowner can in many cases ensure notification of the fire department while the fire is still small enough to be stopped or, if necessary, an emergency evacuation by the homeowner. However, no homeowner can be constantly on the lookout for wildfires, particularly at night. It is well known that wildfires may grow exponentially in dry weather, steep terrain or in high winds. Due to the exponential growth of wildfires, a wildfire must be attacked early or it quickly grows too large and hazardous for a direct attack.

Early attack of a wildfire depends on early detection. For example, if a one-foot fire doubles its diameter every five minutes, it would take 39 minutes to become a one acre blaze, then quickly blows up to 100 acres in the next 16 minutes. Since fire department response times are typically 20 minutes and such quickly-growing fires cannot be safely attacked beyond approximately two acres in size, the fire must be detected and the fire department notified within the first 20 minutes of the fire or the opportunity to stop the fire will have passed. The doubling time can be much shorter in high wind conditions. High winds are additionally dangerous since they often initiate power line arcing, which may cause the power line to break and fall to the ground, thereby immediate setting light fuels on fire. Therefore, it would be desirable to detect power line arcing, even if a fire has not yet started. Then, fire crews may wet down areas downwind of an arcing wire before a fire has begun.

Theory of the method

While numerous flame sensors, many of which respond to UVC photons emitted by hydrocarbon flames, are commercially available, these sensors are typically designed to respond to flames within approximately fifty meters. To be useful, however, a wildfire sensor should detect fires at much longer distances, for example, up to a mile away. Also, a wildfire sensor should be capable of detecting small electrical sparks, such as from arcing power lines, which are common precursors to wildfires. Given geometrical considerations, one might logically assume that a sensor which detects a 0.01 meter diameter flame at 5 meters would be capable of detecting a 1.0 meter diameter flame at 500 meters and, by extension, a 10 meter flame at 5000 meters. However, in the case of UVC detection, atmospheric oxygen absorbs approximately half of the UVC signal every 160 meters, and, additionally, the terrestrial half-power point of UV due to O_2 absorption increases dramatically with wavelength (e.g., the half power point is approximately 60 meters for a wavelength of 210 run, 130 meters at 220 nm, 230 meters at 230 nm, 480 meters at 240 nm, 1150 meters at 250 nm, etc.). In other words, over the course of a one mile path for a UVC wavelength of approximately 225nm as an example, 99.9% of the UVC signal is absorbed by the atmosphere (UVC is substantially blocked by stratospheric ozone), thereby leaving just one tenth of one percent for detection. Moreover, currently available UV detectors are limited in usefulness in sunlight because the sun also radiates ultraviolet radiation. Since sunlight contains ultraviolet radiation in the UVC and UVC as well as UVC ranges, a UV detector for detection of weak and/or distant flames or arcs must be able to ignore UVA and UVB radiation while being sensitive to UVC radiation such that the sensor is essentially blind to sunlight but is highly sensitive to both flames and electrical arcs. That is, the sensor must be highly sensitive in a range within the UVC range (particularly from 230 nm to 280 nm which are not absorbed by O_2) while exhibiting much lower responsivity at wavelengths, for example, longer than 280 nm that are not absorbed by $O_{3.}$.

In order for a UV sensor to detect weak and/or distant flame or electrical arc, the sensor must be highly sensitive to a selected range of UVC radiation. However, most UVC radiation is blocked by tropospheric atmosphere, particularly by oxygen. Since there exists significant overlap between the absorption bands of tropospheric oxygen (O_2) and stratospheric oxygen (O_3), an ideal UV sensor should operate in a spectral region between 240 nm and 270 nm in order to remotely detect the presence of wildfire and/or electrical arc.

Unfortunately, ideal detectors which operate in this limited ultraviolet radiation range are not currently available. While highly effective, absorptive bandpass filters of cobalt glass are available, no such filter is currently available with such exacting specifications. As an alternative, interference filters may be designed to specifically pass only wavelengths between 240 nm and 270 nm, but interference filters are expensive, have limited field of view (i.e., exhibits high angle sensitivity) and generally do not provide sufficient wavelength rejection at wavelengths longer than 280 nm. The angle sensitivity is particularly problematic in fire detection since it is desirable to have one detector to cover a large angular field of view.

Recently, specialized semiconductor photodiodes have been developed under DARPA with the goal of targeting the UVC band of wavelengths which is substantially blocked by stratospheric O_3 but is largely transmitted by tropospheric $O_{2.}$ The efforts are generally aimed at purposes of, for example, tracking missiles and other such projectiles. However, the UVB rejection of such photodiodes thus far has been limited to approximately 30 dB. Such values of UVB rejection may suffice for military purposes, but effective detection of distant wildfires and electrical arcs would require that the response to UVB relative to the desired band of UVC radiation should be reduced at least 25 dB at 280 nm, 45 dB at 290 nm, 75 dB at 300 nm, 90 dB at 310 nm and 100 dB at 320 nm. Very few detectors can meet such UVB rejection requirements, and still fewer achieve such values of UVB radiation rejection over a hemispherical field of view. Additionally, since the spectral emissions of various hydrocarbon flames may or may not be adequately similar and the UVC emissions from such flames are largely re-absorbed on passage through the plasmas of the various flames, the UV spectra of various flames may differ [4].

In a conventional "photon counting" mode of operation of a UVC photo-electric avalanche detector, the presence of extraneous noise counts precludes simply increasing the circuit gain in order to compensate for reduced signal levels. As a result, detection of small or distant fires is difficult at best and typically fraught with the problem of unacceptable false alarms.

One type of photo-electric avalanche detector is the Geiger-Mueller detector, which was originally invented in 1928 for detection of gamma rays. Geiger-Mueller detectors (or GM tubes) can and have been adapted for use as UV detectors. These adapted GM tubes employ the photoelectric effect to strongly reject photons whose energies fall below the work function of a photocathode. Like the original GM tubes, these adaptations employ a low pressure gas to achieve avalanche gain in a strong electric field when an incident UV photon of the correct wavelength succeeds in knocking loose an electron from the photocathode. As different photocathode metals exhibit different work functions, different GM tubes may detect different UV wavelengths. For example, nickel ideally rejects any wavelength longer than 247nm; tungsten ideally rejects any wavelength longer than 274 nm; and molybdenum ideally rejects any wavelength longer than 295nm. However, when placed at above absolute zero temperatures and due to crystal structure imperfections, these cut-off wavelength values blur considerably. Furthermore, although GM tubes commonly exhibit a response peak at around 200nm, the presence of atmospheric O_2 shifts the peak of the already weak UV signal from a fire toward 250 nm. As a result, the rather unpredictable response of GM tubes to solar UVB radiation around 280 nm becomes critical to maintaining an acceptable signal-to-noise (SNR). For instance, although nickel cathode GM tubes have a much lower response to ultraviolet radiation at 250 nm in comparison to molybdenum or tungsten based devices, nickel devices may also exhibit a high enough responsivity to solar radiation greater than 280 nm so as to make the SNR of the device intolerable in remote fire detection applications. Poisson or "shot" noise in the signal as well as cosmic ray background noise becomes problematic in the attempt to extract the fire signal from the background noise.

One example of a compact GM tube for use in fire detectors and alarms is UV TRON.RTM. R2868 [1] available from Hamamatsu Corporation. According to the specification provided with the device, the R2868 exhibits a narrow spectral sensitivity in the 185 to 260 nm range with a wide angular sensitivity so as to detect, for example, a cigarette lighter flame at "a distance of more than 5 m" and "corona discharge of high-voltage transmission lines."[1] However, the specification of R2868 lists the background noise characteristic of the device at 10 cpm Max under room illumination and operating conditions. Since the background noise characteristic further worsens in sunlight conditions, this background noise characteristic of R2868 as supplied by the manufacturer is unacceptable in detecting the presence of wildfire and electrical arcs at long distances. Also, the driver/processor circuit available from Hamamatsu for use with R2868 employs a fixed integration period time integration circuit which triggers the generation of an alarm signal when the photon count received at R2868 reaches a user-specified threshold value during a given integration period. In the Hamamatsu driving circuit, if the photon count is even just slightly below the threshold value at the end of any given integration period, then the photon count is reset to zero at the end of the integration period [2]. This time integration method is inadequate for use in the long distance detection of wildfires and flames because the photon count over time may be very low for a long period of time but increase exponentially over a short time period. Since early detection is key in this application, the resetting of the photon count at the end of each integration period may lead to the loss of precious time in detection of far away but significant fire sources.

It should be noted that, since GM tubes exhibit individual variations in spectral responsivity characteristics, a certain percentage of GM tubes may be sufficiently "solar blind" so as to be suitable for the present application of long distance flame detection, particularly when combined with the exponentially decaying time integration method of the present invention. However, it has been found that the average GM tube used in strict accordance with the manufacturer's recommendations will not yield the desired performance in a long distance flame detector for a variety of reasons. Firstly, Applicant has found that the GM tube must subjected to a higher bias voltage than the recommended V_{max} value in order to sufficiently increase its sensitivity to UVC light of 23 0nm to 280 nm, thereby tripling the responsivity of the GM tube to UVC in comparison to its responsivity in this wavelength range at the manufacturer recommended voltage. Secondly, Applicant has found that the plots showing the responsivity peak and the solar spectrum as shown in the manufacturer's specification sheet are misleading because these plots do not take into account the fact that sunlight is much higher in intensity than the UVC radiation emitted by a distant flame. Therefore, although the responsivity plot seems to suggest that the responsivity goes to zero at certain wavelengths, the relative difference in responsivity between the signal wavelength and solar wavelengths must be, for instance, a factor of a billion at 29 5nm and a trillion at 315 nm. The quoted indoor noise specification, as shown in the manufacturer's specification sheet, is 10 cpm. However, in order for the system to function adequately, this noise value must be less than I cpm in sunlight conditions at elevated bias voltage operating conditions, since, when noise counts go up by a factor of ten, sensitivity of the GM tube is driven down by a factor of ten. These differences in desired performance and non-ideal responses can make the difference between timely alerting to the presence of a fire and delaying the emission of an alarm signal until after the flame has grown too large to fight it effectively. Thirdly, detection of remote flames of interest, which may produce just four or five photon counts per minute, requires extremely long integration times to reduce the occurrence of false alarms due to, for example, cosmic rays and signal-shot noise ambiguities. For example the circuit board sold with the Hamamatsu R2868 is designed to trigger an alarm signal when three to nine photon counts are received within a two second interval. It is submitted that this trigger condition is insufficient for the detection of distant flames. On the other hand, the use of the aforedescribed photo-annealing process in combination with the exponentially decaying time integration method of the present invention may raise the yield to nearly 100% and ensure that the GM tube used in the remote wildfire detector system of the present invention will exhibit the appropriate spectral responsivity characteristics necessary to function as an effective device.

It is emphasized that long range flame/electrical arc detection hinges on the recognition by Applicant that the UVC wavelengths around 250 nm (which are emitted by flames from electrical arcs as well as burning vegetation) are transmitted through O_2 but not by O_3. Since a nickel cathode's responsivity at 250 nm is significantly higher than the responsivity at 280 nm, a GM tube with, for instance, a nickel cathode is recognized to be suitable for long distance flame detection [3].

Conclusion

Although each of the aforedescribed embodiments have been illustrated with various components having particular respective orientations, it should be understood that the present invention may take on a variety of specific configurations with the various components being located in a wide variety of positions and mutual orientations and still remain within the spirit and scope of the present invention. Furthermore, suitable equivalents may be used in place of or in addition to the various components, the function and use of such substitute or additional components being held to be familiar to those skilled in the art and are therefore regarded as falling within the scope of the present invention. For example, a variety of materials, such as nickel, molybdenum, tungsten and combinations thereof, may be used as a photocathode within the GM tube. Also, a filter may be used in conjunction with the GM tube in order to further block wavelengths shorter than 230 nm. Additionally, "blinders" or shutters may be attached to the detector system of the present invention so as to prevent the detector system from being triggered by nearby, controlled fire sources such as cigarettes or barbecue grills. A hygrometer, such as those based on hygroscopic calcium chloride or magnesium chloride as a resistor in parallel with resistor, may also be added to the flame detection system of the present invention. Such a hygrometer would function to reduce the RC time constant when humidity is high. In this way, the flame sensor would be at maximum sensitivity only when conditions are very dry, thereby reducing the likelihood of an unwanted false alarm resulting from the presence of controlled, non-wildfire UVC sources (such as an arc-welder, bug-zapper, tiki-torch, etc.) at times of high humidity when the urgency of detection is reduced. As another modification, the alarm signal produced by the system may be fed into a phone dialer to automatically notify authorities when the homeowner is not home, for instance. For example, an entire fire district may be covered by an autonomous array of such detectors by networking them to a plurality of fire department officers in order to avoid the possibility of a single-point failure to alert authorities to the presence of a fire.

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