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(71) **Applicant: GOVERNMENT OF THE UNITED STATES OF AMERICA, AS REPRESENTED BY THE SECRETARY OF COMMERCE** [US/US]; National Institute of Standards and Technology, 100 Bureau Drive, Gaithersburg, Maryland 20899 (US).

(72) **Inventors: MENSCH, Amy Elizabeth**; NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY, 100 Bureau Drive, MS 1052, Gaithersburg, Maryland 20899 (US). **FALKENSTEIN, Ryan Leon**; NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY, 100 Bureau Drive, MS 1052, Gaithersburg, Maryland 20899 (US). **CLEARY, Thomas George**; NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY, 100 Bureau Drive, MS 1052, Gaithersburg, Maryland 20899 (US). **FERNANDEZ, Marco Gabriel**; NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY, 100 Bureau Drive, MS 1052, Gaithersburg, Maryland 20899 (US).

(74) **Agent: BIS, Richard F.**; National Institute of Standards and Technology, 100 Bureau Drive, Gaithersburg, Maryland 20899 (US).

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(54) **Title:** APPARATUS AND METHOD FOR PHOTOACOUSTIC MEASUREMENT OF SOOT DEPOSITION

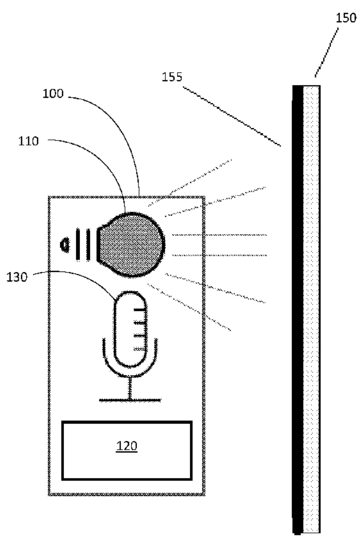

FIG. 1

(57) **Abstract:** An apparatus and method for measuring soot deposition includes irradiating a soot deposit with pulsed electromagnetic radiation configured to cause a rapid-enough expansion of the soot deposit to cause an acoustic pressure wave, sensing the pressure wave with an acoustic measurement device, and, based on the received signal and calibration data, determining the amount of soot deposited.

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[Continued on next page]

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APPARATUS AND METHOD FOR PHOTOACOUSTIC MEASUREMENT OF SOOT DEPOSITION

Related Applications

This application claims the benefit of U.S. Provisional Patent Application Serial No. 63/538,106 (filed September 13, 2023), which is herein incorporated by reference in its entirety.

Federally-Sponsored Research and Development

This invention was made with United States Government support from the National Institute of Standards and Technology (NIST), an agency of the United States Department of Commerce. The Government has certain rights in this invention.

Copyright Notice

Field of Invention

The present invention relates generally to forensic fire reconstruction, and more particularly to a photoacoustic method of fire reconstruction.

Background

In forensic fire reconstruction, investigators attempt to draw conclusions about fire origin, the direction of fire progression, and the duration of exposure by relying on the subjective interpretation of post-fire burn patterns for their analysis. The key to burn pattern analysis is characterizing the soot surface deposition that makes up burn patterns and linking the soot deposition to critical elements of the fire, such as the cause, origin, or order of fire progression.

Summary of Invention

However, it is difficult to make accurate measurements of the mass loading of soot deposition on surfaces. Many existing tools for measuring soot deposition, such as a gravimetric target or a conductance gauge, require preparation of the substrate before soot is deposited. These techniques are best suited for experimental measurement, and would be impossible to use in a post-fire scenario.

Therefore, a new measurement tool and process is presented that quantifies soot deposition on surfaces via non-invasive acoustic measurements. The tool includes a variable light source and microphone capable of measuring low acoustic levels. When exposed to a pulsed light source, soot absorbs the generated photons, causing it to heat rapidly and expand. Due to soot's high emissivity, the generated heat quickly dissipates, causing the soot to contract and emit an audible noise, of which its intensity is correlated to the amount (mass) of soot deposited.

Exemplary photoacoustic deposition measurement techniques have potential to be a reliable tool for both forensic analysis to non-invasively and reliably investigate burn patterns in a fire scene for fire reconstruction. Easy-to-use measurement tools that can gather soot deposition data for large areas would greatly benefit the fire research and modeling communities as well, contributing to a better understanding of smoke dynamics and more accurate predictions for life safety, such as predictions of visibility and smoke toxicity.

According to one aspect of the invention a method of measuring soot deposition includes irradiating a soot deposit with a pulse of electromagnetic radiation configured to stimulate an acoustic pressure wave from the soot deposit due to at least one of rapid thermal expansion or rapid thermal contraction; and sensing the pressure wave with an acoustic measurement device, and, based on received acoustic signal and calibration data, determining an amount of soot deposited.

Optionally, the method also includes subtracting a baseline acoustic signal from the received acoustic signal, thereby isolating effects of the soot deposit on the received acoustic signal.

Optionally, the pulsed electromagnetic radiation has a wavelength of approximately 1047 nm.

Optionally the method also includes generating pulsed electromagnetic radiation in one or more visible wavelengths visibly indicating to a user that a measurement has been taken.

Optionally, the method includes irradiating a soot deposit with pulsed electromagnetic radiation of a different wavelength configured to stimulate a different acoustic pressure wave from the soot deposit due to at least one of rapid thermal expansion or rapid thermal contraction.

According to another aspect of the invention, a photoacoustic measurement device for measuring soot deposition includes a pulsed electromagnetic radiation source configured to emit electromagnetic radiation at a soot deposit; an acoustic measurement device configured to sense a pressure wave originating from the soot deposit; and a controller configured to determine the amount of soot deposited based on a received acoustic signal and calibration data.

Optionally, the pulsed electromagnetic radiation source is configured to emit a pulse of electromagnetic radiation tending to cause a rapid-enough expansion of the soot deposit to cause an acoustic pressure wave.

Optionally, the pulsed electromagnetic radiation has a wavelength of approximately 1047 nm.

Optionally, the pulsed electromagnetic radiation source is a camera flash.

Optionally, the pulsed electromagnetic radiation source is a pulsed laser.

Optionally, the pulsed electromagnetic radiation source is time sliced to generate light at one or more visible wavelengths, and at about 1047 nm, thereby visually indicating to a user that a measurement has been taken.

Optionally, the pulsed electromagnetic radiation source is time sliced to generate light at two or more wavelengths that both stimulate acoustic responses from soot.

Optionally, the acoustic measurement device is a standard microphone.

Optionally, the acoustic measurement device is a focused microphone.

Optionally, the acoustic measurement device is a laser microphone.

The foregoing and other features of the invention are hereinafter described in greater detail with reference to the accompanying drawings.

Brief Description of the Drawings

FIG. 1 shows a schematic of an exemplary photoacoustic device.

FIG. 2 shows an exemplary process of measuring soot deposition using a photoacoustic measurement device.

FIG. 3 shows an example calibration curve that can be used to calculate the amount of soot deposition based on an acoustic signal.

Detailed Description

Conventional methods to characterize soot deposition quantitatively have demonstrated various limitations or challenges. A non-invasive technique relying on grayscale image analysis was validated for vertical gypsum wallboard exposed to fire. However, since the method assumes soot deposition is correlated with the grayscale coloring of the image, the technique relies on consistent lighting and an opaque white substrate, both of which limit the method's applicability in the field. Other methods used in fire research experiments can provide point measurements of deposition with high accuracy (gravimetric targets) or with time resolved information (conductance gauge), but these methods require modification of the substrate prior to exposure. Therefore, a reliable non-invasive measurement technique for soot deposition, independent of prior modification of the substrate surface, would enable a more quantitative analysis of burn patterns to better understand critical parameters in fire investigations.

Exemplary embodiments of the invention quantify soot deposition on surfaces via non-invasive acoustic measurements with no preparation of the substrate required a priori. The photoacoustic measurement itself can be performed within a few seconds and can be replicated easily to collect soot deposition measurements across large surface areas.

When exposed to a pulsed light source, black soot readily absorbs the generated photons, causing it to heat rapidly and expand. As used here, a pulse of light means the light generation lasts for between approximately 0.1 to 20 milliseconds in length. Due to soot's high emissivity, the generated heat quickly dissipates, resulting in contraction of the soot and emitting an audible noise. The noise is translated into an audio signal via a microphone, which quantifies the intensity of the sound which is correlated to the concentration of soot deposition on the substrate. The acoustic response can also be affected by the surface material, the intensity of the light source, the distance of the light source from the surface, the distance of the surface from the microphone, and the sensitivity of the microphone. Therefore, the tool can make use of calibrations for the acoustic response from known soot deposition loadings on common surface materials with the same pulsed light source and microphone parameters.

This photoacoustic deposition measurement technique has potential to be a reliable tool for both forensic analysis to non-invasively and reliably investigate burn patterns in a fire scene for fire reconstruction. This easy-to-use measurement tool that can gather soot deposition data for large areas would greatly benefit the fire research and modeling communities as well, contributing to a better understanding of smoke dynamics and more accurate predictions for life safety, such as predictions of visibility and smoke toxicity.

Referring first to FIG. 1, an exemplary photoacoustic measurement device 100 is shown in schematic representation.

A pulsed light source (photon source) 110 may be controlled to emit electromagnetic radiation at a sooty substrate150. In some embodiments, the pulsed light source 110 is controlled fully manually, while in other embodiments, the pulsed light source 110 may be controlled semi or fully autonomously with a controller 120. Any suitable pulsed light source may be used, for example and without limitation, a camera flash, a pulsed laser, or a custom light source. The pulsed light source 110 should be of sufficient intensity to cause a detectable acoustic response from the sooty substrate.

The pulsed light source may be more or less focused, depending on the amount of area intended to be sampled—the larger the area exposed to the pulsed light source, the larger the area that will acoustically respond. In some exemplary embodiments, a small area of interest may be desired, and therefore a very focused beam of light (or a pulsed laser) may be used. In some exemplary embodiments, a pulsed light beam may be scanned over an area—

analogously to a LIDAR sensor—in order to make a high-fidelity mapping of a sooty area. In other exemplary embodiments, an area of interest may be on the order of square centimeters, square inches, or square feet. In such cases, a simpler device with a pulsed light source more like a camera flash may be used.

The pulsed light source 110 may be any appropriate wavelength of light to cause such an acoustic response, and is, in some preferred embodiments, in the visible and/or infrared spectrum. In one preferred embodiment, pulsed light having a wavelength of 1047 nm wavelength is used for measuring the photoacoustic signal from soot 155 because 1047 nm lasers can be obtained with very high power and black carbon has a strong absorption at this wavelength. In one exemplary embodiment, the photoacoustic measurement device may be time sliced to control the pulsed light source to generate light at other wavelengths, such as one or more nominally visible wavelengths, and then at 1047 nm, thereby to visually indicate to a user that a measurement has been taken, or to produce more than one acoustic measurement stimulated by different optical wavelengths which may produce other information about the soot 155 than a single wavelength might generate.

Exemplary photoacoustic measurement devices also include an acoustic measurement device (acoustic detector) 130 for sensing the acoustic signal of the soot 155 heated by the light source 110. Any suitable acoustic measurement device may be used including, for example and without limitation, a standard or focused microphone or a laser microphone. Preferably, the microphone used is well selected and calibrated to receive signals characteristic of energized soot and to reject noise and other signals.

Optionally, the entire measurement procedure may be automated using the controller 120 or other computer external or internal to the body of the measurement device 100. The other components of the measurement device 100 may be connected to the computer by any suitable method, including a serial port, IEEE 488 connection, or direct digital control. Any suitable software may be used to interface the computer 120 with the other components of the measurement device. The measurement device may be calibrated before, during, or after a measurement.

The computer 120 may use an algorithm to process the received acoustic signal. The algorithm may calculate the mass weight of soot on the substrate, which is related to the measured acoustic pressure as shown, for example, in FIG.3.

Referring now to FIG. 2, an exemplary process for measuring soot deposition via photoacoustics is shown at 200. When soot has been observed to have been deposited on a substrate at block 210, the surface of the substrate may be exposed to light, rapidly, from a controlled pulsed light source at block 220. The pulse of light emitted by the controlled light source is absorbed onto the substrate and soot at block 230, and the soot particulates are rapidly heated, causing rapid expansion of those particles at block 240. This expansion (and/or the rapid contraction by the relatively-rapidly-cooling particulates) generates a pressure wave at block 250. This pressure wave may be detected by an acoustic detector (microphone) at block 260. A second acoustic signal—one obtained from a non-soot substrate exposed to the same light source—may be subtracted from the first, sooty acoustic signal, thereby isolating the effects of the soot on the acoustic signal at block 270. This differential acoustic signal may be processed by a computer or otherwise compared to a calibration curve at block 280 to obtain an indirect/inferred measurement of the amount of soot deposited on the substrate at block 290.

The processes described herein may be embodied in, and fully automated via, software code modules executed by a computing system that includes one or more general purpose computers or processors. The code modules may be stored in any type of non-transitory computer-readable medium or other computer storage device. Some or all the methods may alternatively be embodied in specialized computer hardware. In addition, the components referred to herein may be implemented in hardware, software, firmware, or a combination thereof.

Many other variations than those described herein will be apparent from this disclosure. For example, depending on the embodiment, certain acts, events, or functions of any of the algorithms described herein can be performed in a different sequence, can be added, merged, or left out altogether (e.g., not all described acts or events are necessary for the practice of the algorithms).

Moreover, in certain embodiments, acts or events can be performed concurrently, e.g., through multi-threaded processing, interrupt processing, or multiple processors or processor cores or on other parallel architectures, rather than sequentially. In addition, different tasks or processes can be performed by different machines and/or computing systems that can function together.

Any logical blocks, modules, and algorithm elements described or used in connection with the embodiments disclosed herein can be implemented as electronic hardware, computer software, or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, and elements have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. The described functionality can be implemented in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the disclosure.

The various illustrative logical blocks and modules described or used in connection with the embodiments disclosed herein can be implemented or performed by a machine, such as a processing unit or processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A processor can be a microprocessor, but in the alternative, the processor can be a controller, microcontroller, or state machine, combinations of the same, or the like. A processor can include electrical circuitry configured to process computer-executable instructions. In another embodiment, a processor includes an FPGA or other programmable device that performs logic operations without processing computer-executable instructions. A processor can also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration. Although described herein primarily with respect to digital technology, a processor may also include primarily analog components. For example, some or all of the signal processing algorithms described herein may be implemented in analog circuitry or mixed analog and digital circuitry. A computing environment can include any type of computer system, including, but not limited to, a computer system based on a microprocessor, a mainframe computer, a digital signal processor, a portable computing device, a device controller, or a computational engine within an appliance, to name a few.

The elements of a method, process, or algorithm described in connection with the embodiments disclosed herein can be embodied directly in hardware, in a software module stored in one or more memory devices and executed by one or more processors, or in a combination of the two. A software module can reside in RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, registers, hard disk, a removable disk, a CD-ROM, or any other form of non-transitory computer-readable storage medium, media, or physical computer storage known in the art. An example storage medium can be coupled to the processor such that the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium can be integral to the processor. The storage medium can be volatile or nonvolatile.

While one or more embodiments have been shown and described, modifications and substitutions may be made thereto without departing from the spirit and scope of the invention. Accordingly, it is to be understood that the present invention has been described by way of illustrations and not limitation. Embodiments herein can be used independently or can be combined.

All ranges disclosed herein are inclusive of the endpoints, and the endpoints are independently combinable with each other. The ranges are continuous and thus contain every value and subset thereof in the range. Unless otherwise stated or contextually inapplicable, all percentages, when expressing a quantity, are weight percentages. The suffix (s) as used herein is intended to include both the singular and the plural of the term that it modifies, thereby including at least one of that term (e.g., the colorant(s) includes at least one colorants). Option, optional, or optionally means that the subsequently described event or circumstance can or cannot occur, and that the description includes instances where the event occurs and instances where it does not. As used herein, combination is inclusive of blends, mixtures, alloys, reaction products, collection of elements, and the like.

As used herein, a combination thereof refers to a combination comprising at least one of the named constituents, components, compounds, or elements, optionally together with one or more of the same class of constituents, components, compounds, or elements.

All references are incorporated herein by reference.

The use of the terms “a,” “an,” and “the” and similar referents in the context of describing the invention (especially in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. It can further be noted that the terms first, second, primary, secondary, and the like herein do not denote any order, quantity, or importance, but rather are used to distinguish one element from another. It will also be understood that, although the terms first, second, etc. are, in some instances, used herein to describe various elements, these elements should not be limited by these terms. For example, a first current could be termed a second current, and, similarly, a second current could be termed a first current, without departing from the scope of the various described embodiments. The first current and the second current are both currents, but they are not the same condition unless explicitly stated as such.

The modifier about used in connection with a quantity is inclusive of the stated value and has the meaning dictated by the context (e.g., it includes the degree of error associated with measurement of the particular quantity). The conjunction or is used to link objects of a list or alternatives and is not disjunctive; rather the elements can be used separately or can be combined together under appropriate circumstances.

Although the invention has been shown and described with respect to a certain embodiment or embodiments, it is obvious that equivalent alterations and modifications will occur to others skilled in the art upon the reading and understanding of this specification and the annexed drawings. In particular regard to the various functions performed by the above described elements (components, assemblies, devices, compositions, etc.), the terms (including a reference to a "means") used to describe such elements are intended to correspond, unless otherwise indicated, to any element which performs the specified function of the described element (i.e., that is functionally equivalent), even though not structurally equivalent to the disclosed structure which performs the function in the herein illustrated exemplary embodiment or embodiments of the invention. In addition, while a particular feature of the invention may have been described above with respect to only one or more of several illustrated embodiments, such feature may be combined with one or more other features of the other embodiments, as may be desired and advantageous for any given or particular application.

Claims

What is claimed is:

1. A method of measuring soot deposition comprises:

irradiating a soot deposit with pulsed electromagnetic radiation configured to stimulate an acoustic pressure wave from the soot deposit due to at least one of rapid thermal expansion or rapid thermal contraction; and

sensing the pressure wave with an acoustic measurement device, and, based on received acoustic signal and calibration data, determining an amount of soot deposited.

2. The method of claim 1, further comprising:

subtracting a baseline acoustic signal from the received acoustic signal, thereby isolating effects of the soot deposit on the received acoustic signal.

3. The method of any preceding claim, wherein the pulsed electromagnetic radiation has a wavelength of approximately 1047 nm.

4. The method of any preceding claim, further comprising:

generating pulsed electromagnetic radiation in one or more visible wavelengths visibly indicating to a user that a measurement has been taken.

5. The method of any preceding claim, further comprising:

irradiating a soot deposit with pulsed electromagnetic radiation of a different wavelength configured to stimulate a different acoustic pressure wave from the soot deposit due to at least one of rapid thermal expansion or rapid thermal contraction.

6. A photoacoustic measurement device for measuring soot deposition comprises:

an electromagnetic radiation source configured to emit pulsed electromagnetic radiation at a soot deposit;

an acoustic measurement device configured to sense a pressure wave originating from the soot deposit; and

a controller configured to determine the amount of soot deposited based on a received acoustic signal and calibration data.

7. The photoacoustic measurement device of claim 6, wherein the pulsed electromagnetic radiation source is configured to emit electromagnetic radiation tending to cause a rapid-enough expansion of the soot deposit to cause an acoustic pressure wave.

8. The photoacoustic measurement device of any preceding claim, wherein the pulsed electromagnetic radiation has a wavelength of approximately 1047 nm.

9. The photoacoustic measurement device of any preceding claim, wherein the pulsed electromagnetic radiation source is a camera flash.

10. The photoacoustic measurement device of any preceding claim, wherein the pulsed electromagnetic radiation source is a laser.

11. The photoacoustic measurement device of any preceding claim, wherein the pulsed electromagnetic radiation source is time sliced to generate light at one or more visible wavelengths, and at about 1047 nm, thereby visually indicating to a user that a measurement has been taken.

12. The photoacoustic measurement device of any preceding claim, wherein the pulsed electromagnetic radiation source is time sliced to generate light at two or more wavelengths that both stimulate acoustic responses from soot.

13. The photoacoustic measurement device of any preceding claim, wherein the acoustic measurement device is a standard microphone.

14. The photoacoustic measurement device of any preceding claim, wherein the acoustic measurement device is a focused microphone.

15. The photoacoustic measurement device of any preceding claim, wherein the acoustic measurement device is a laser microphone.

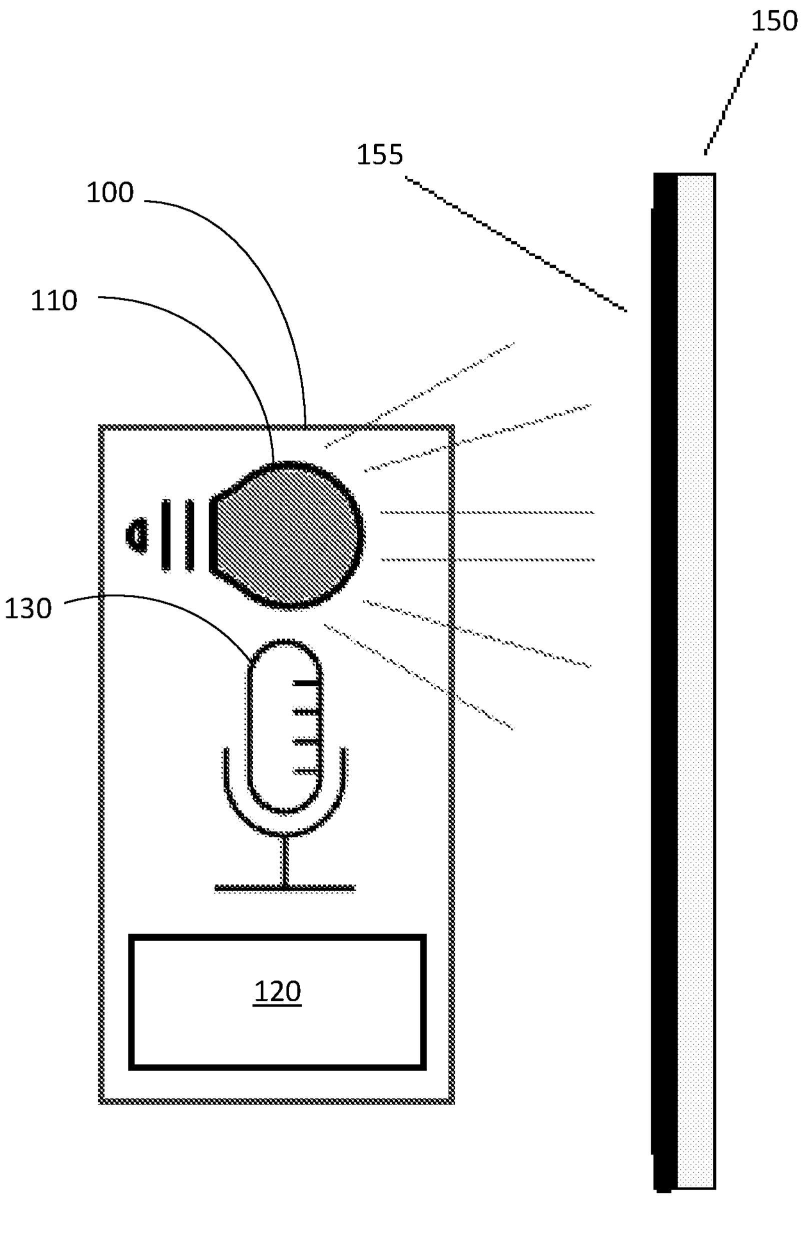

FIG. 1

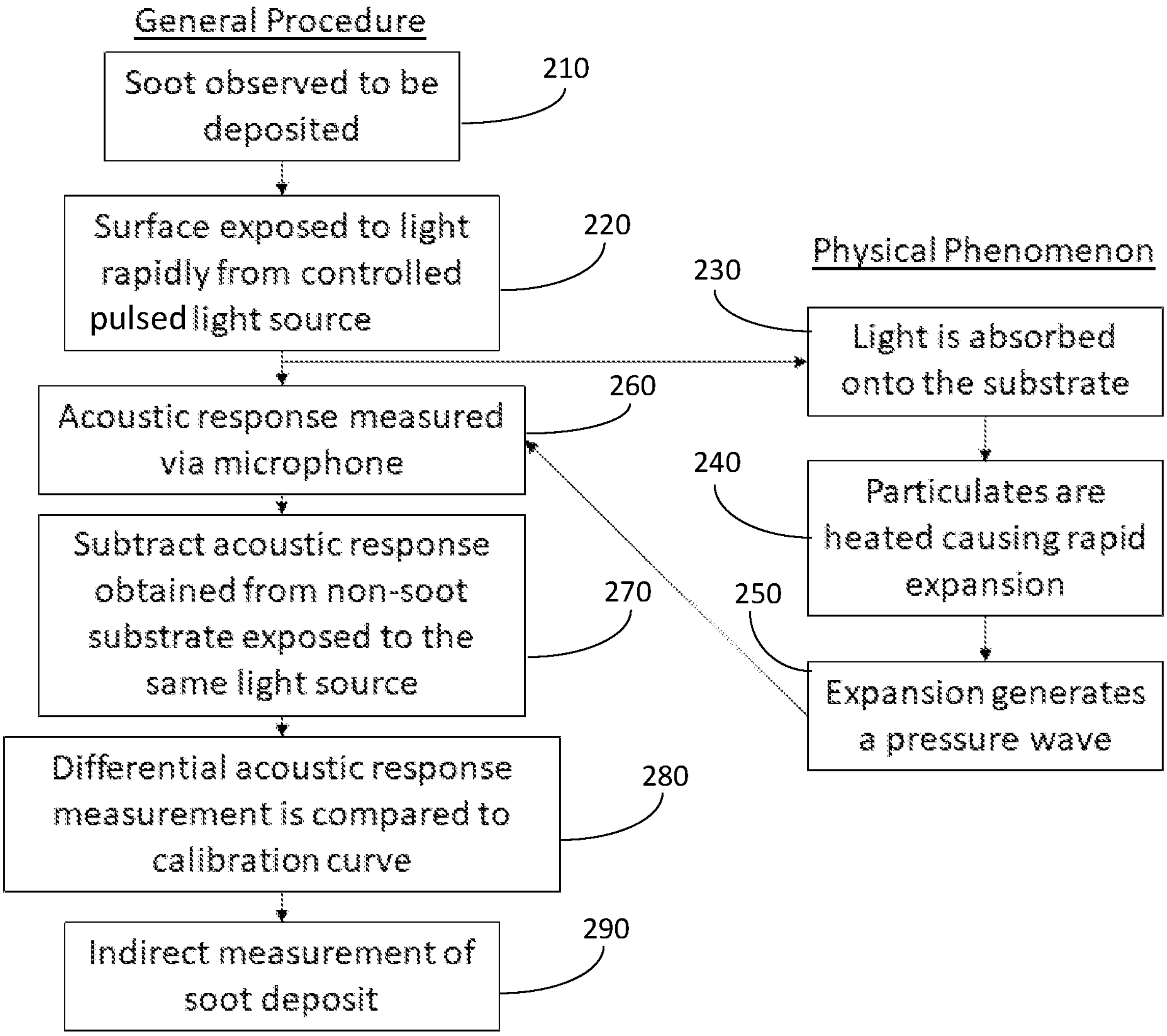
General Procedure
Soot observed to be deposited
210
Surface exposed to light rapidly from controlled pulsed light source
220
Acoustic response measured via microphone
260
Subtract acoustic response obtained from non-soot substrate exposed to the same light source
270
Differential acoustic response measurement is compared to calibration curve
280
Indirect measurement of soot deposit
290
Physical Phenomenon
230
Light is absorbed onto the substrate
240
Particulates are heated causing rapid expansion
250
Expansion generates a pressure wave

FIG. 2

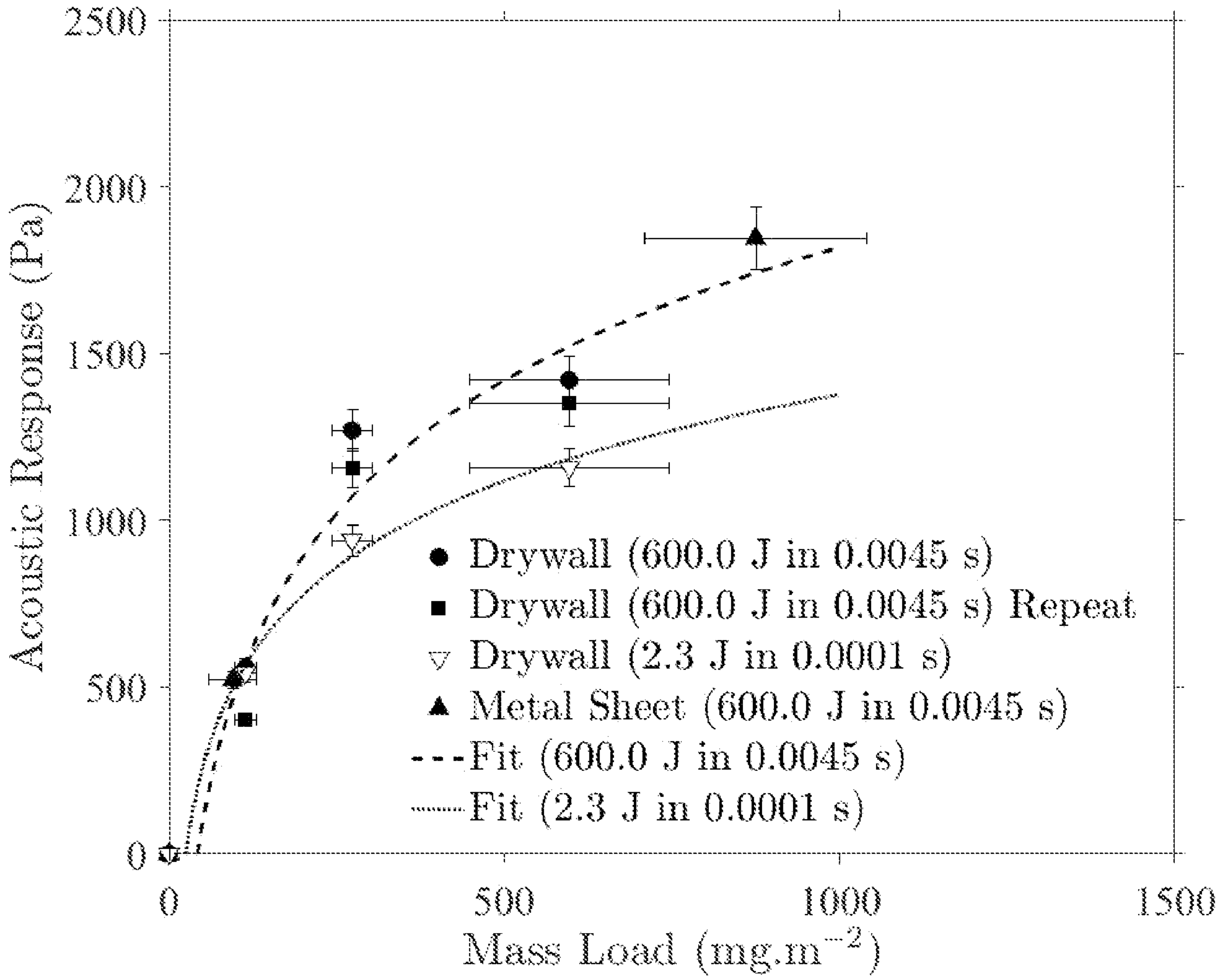
2500
2000
1500
1000
500
0
Acoustic Response (Pa)
0
500
1000
1500
Mass Load (mg.m⁻²)
Drywall (600.0 J in 0.0045 s)
Drywall (600.0 J in 0.0045 s) Repeat
Drywall (2.3 J in 0.0001 s)
Metal Sheet (600.0 J in 0.0045 s)
Fit (600.0 J in 0.0045 s)
Fit (2.3 J in 0.0001 s)

FIG. 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2024/046755

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01N29/24 G01N29/44
ADD.

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)
G01N

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

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

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	BENNETT C A AND PATTY R R: "Monitoring particulate carbon collected on Teflon filters: an evaluation of photoacoustic and transmission techniques", APPLIED OPTICS, OPTICAL SOCIETY OF AMERICA, WASHINGTON, DC, US, vol. 21, no. 3, February 1982 (1982-02), pages 371-374, XP002100250, ISSN: 0003-6935, DOI: 10.1364/AO.21.000371 abstract; figure 6 the whole document ----- -/--	1-15

[X] Further documents are listed in the continuation of Box C.

[ ] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 December 2024	03/01/2025

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Barthélemy, Matthieu

3

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	ARNOTT W PATRICK ET AL: "Nitrogen dioxide and kerosene-flame soot calibration of photoacoustic instruments for measurement of light absorption by aerosols", REVIEW OF SCIENTIFIC INSTRUMENTS, AMERICAN INSTITUTE OF PHYSICS, 2 HUNTINGTON QUADRANGLE, MELVILLE, NY 11747, vol. 71, no. 12, December 2000 (2000-12), pages 4545-4552, XP012037885, ISSN: 0034-6748, DOI: 10.1063/1.1322585 abstract page 4550 -----	3,8
A	JUSSI ROSSI ET AL: "Photoacoustic characteristics of carbon-based infrared absorbers", ARXIV.ORG, CORNELL UNIVERSITY LIBRARY, 201 OLIN LIBRARY CORNELL UNIVERSITY ITHACA, NY 14853, 24 November 2020 (2020-11-24), XP081828340, abstract; figure 5a the whole document -----	3,8,11, 12,15
A	WANG GAOXUAN ET AL: "FILTER-FREE LIGHT ABSORPTION MEASUREMENT OF VOLCANIC ASHES AND AMBIENT PARTICULATE MATTER USING MULTI-WAVELENGTH PHOTOACOUSTIC SPECTROSCOPY", PROGRESS IN ELECTROMAGNETICS RESEARCH (P IE R), vol. 166, January 2019 (2019-01), pages 59-74, XP093232169, US ISSN: 1559-8985, DOI: 10.2528/PIER19100603 abstract pages 60-61 -----	5,11,12
A	COSTA D. ET AL: "Dry aerosol particle deposition on indoor surfaces: Review of direct measurement techniques", AEROSOL SCIENCE AND TECHNOLOGY., vol. 56, no. 3, 4 March 2022 (2022-03-04), pages 261-280, XP093232128, US ISSN: 0278-6826, DOI: 10.1080/02786826.2021.2013431 the whole document -----	1,6

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International application No
PCT/US2024/046755

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X,P	Mensch Amy ET AL: "A Photoacoustic Technique for Measuring Soot Deposition on Surfaces", , 13 March 2024 (2024-03-13), XP093231723, Retrieved from the Internet: URL:https://tsapps.nist.gov/publication/get_pdf.cfm?pub_id=957428 [retrieved on 2024-12-06] the whole document -----	1-15

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