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(54) **FORWARD SCATTER IN PARTICULATE MATTER SENSOR**

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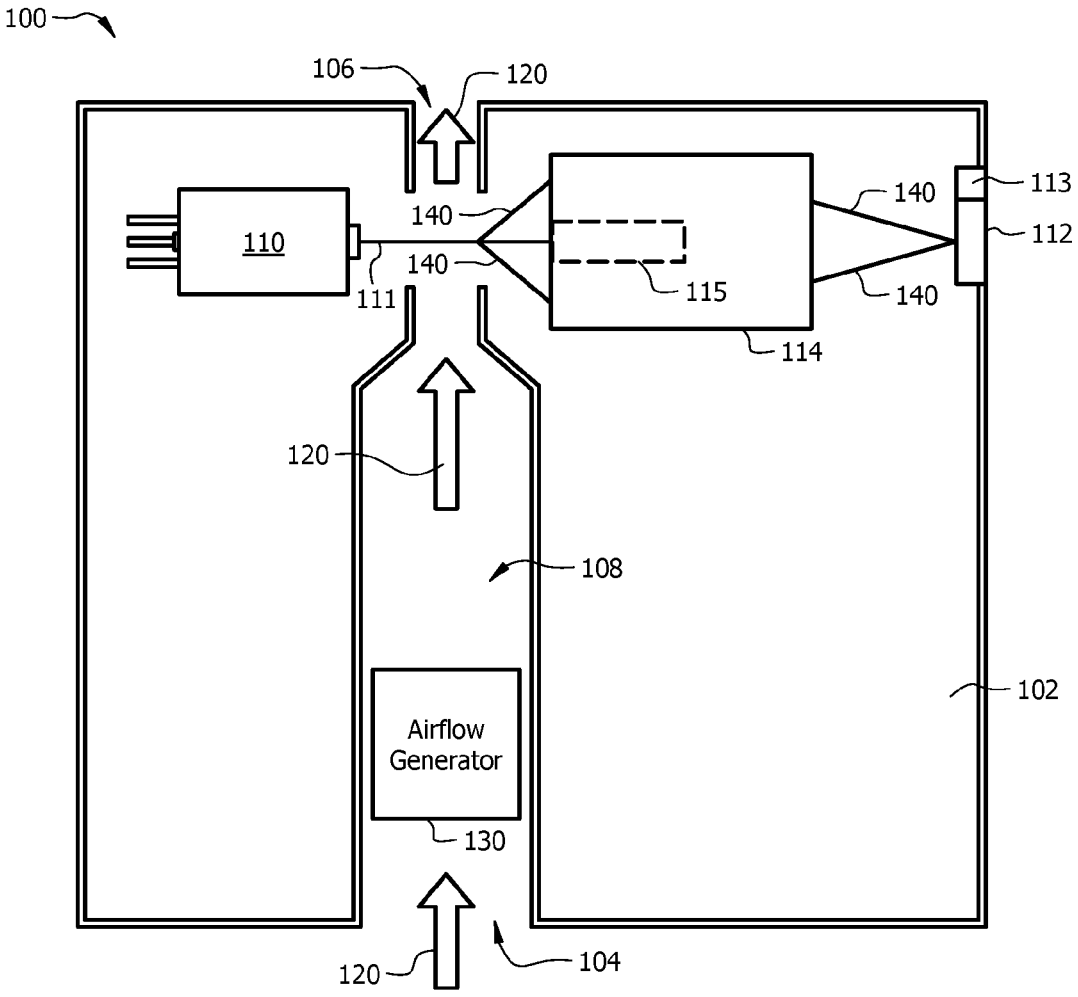
(57) **ABSTRACT**

Embodiments relate generally to systems and methods for detecting particulate matter in the air. A particulate matter sensor may comprise an airflow channel; a light source configured to pass light through the airflow channel; an airflow generator configured to generate airflow into the airflow channel; a waveguide configured to direct light from the light source after it passes through the airflow channel and scatters off of particulate matter within the airflow channel; a photodiode configured to receive light scattered by the waveguide; and a computing device coupled to the photodiode having a processor and a memory storing instructions which, when executed by the processor, determines a mass concentration of particles in the airflow channel based on an output of the photodiode.



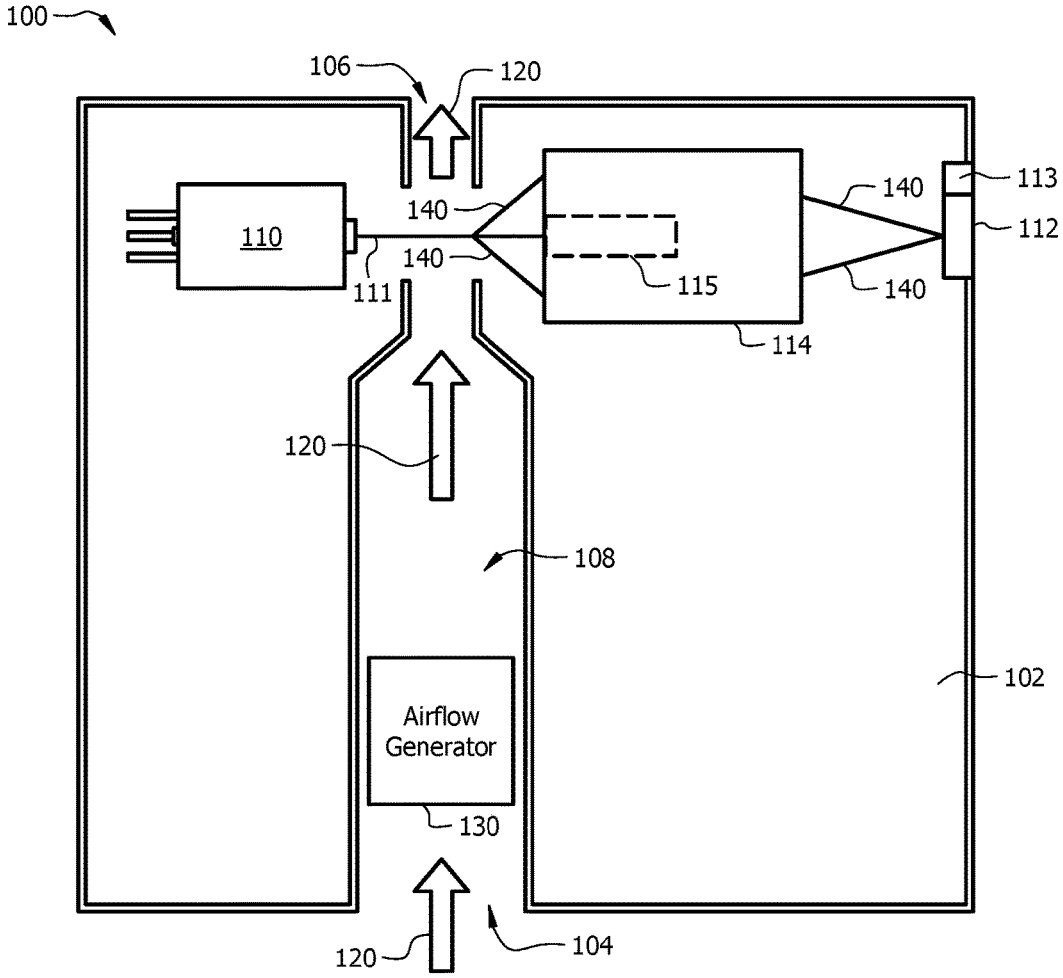

100
106
120
110
140
140
111
140
113
112
115
140
114
120
108
102
Airflow Generator
130
120
104

FIG. 1

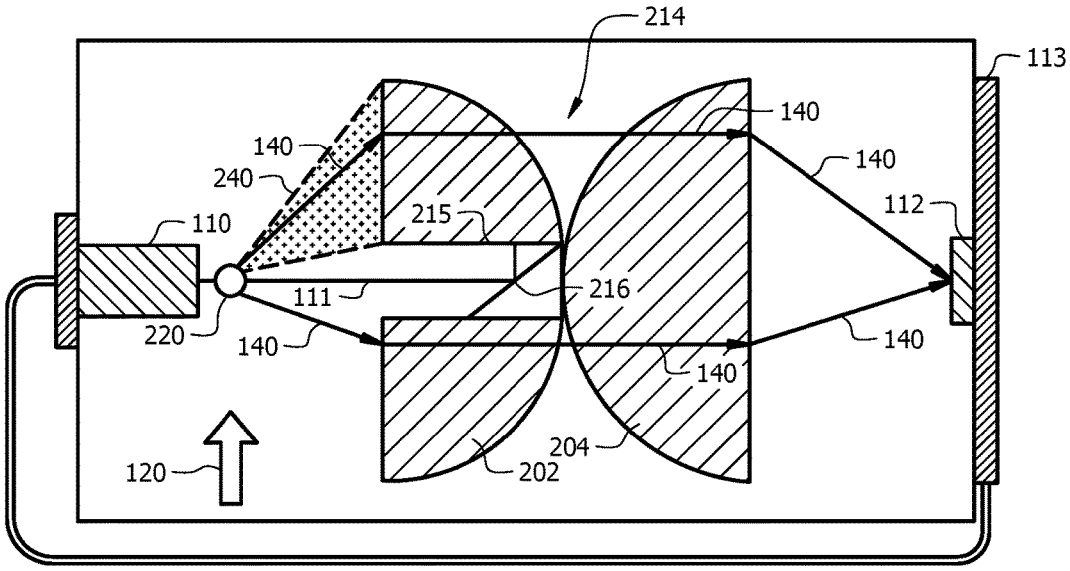

214
113
140
140
240
140
112
110
215
111
216
220
140
140
140
120
204
202

FIG. 2A

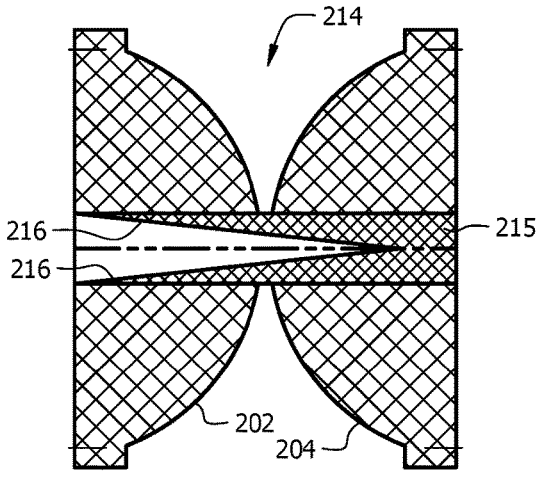

214
216
215
216
202
204

FIG. 2B

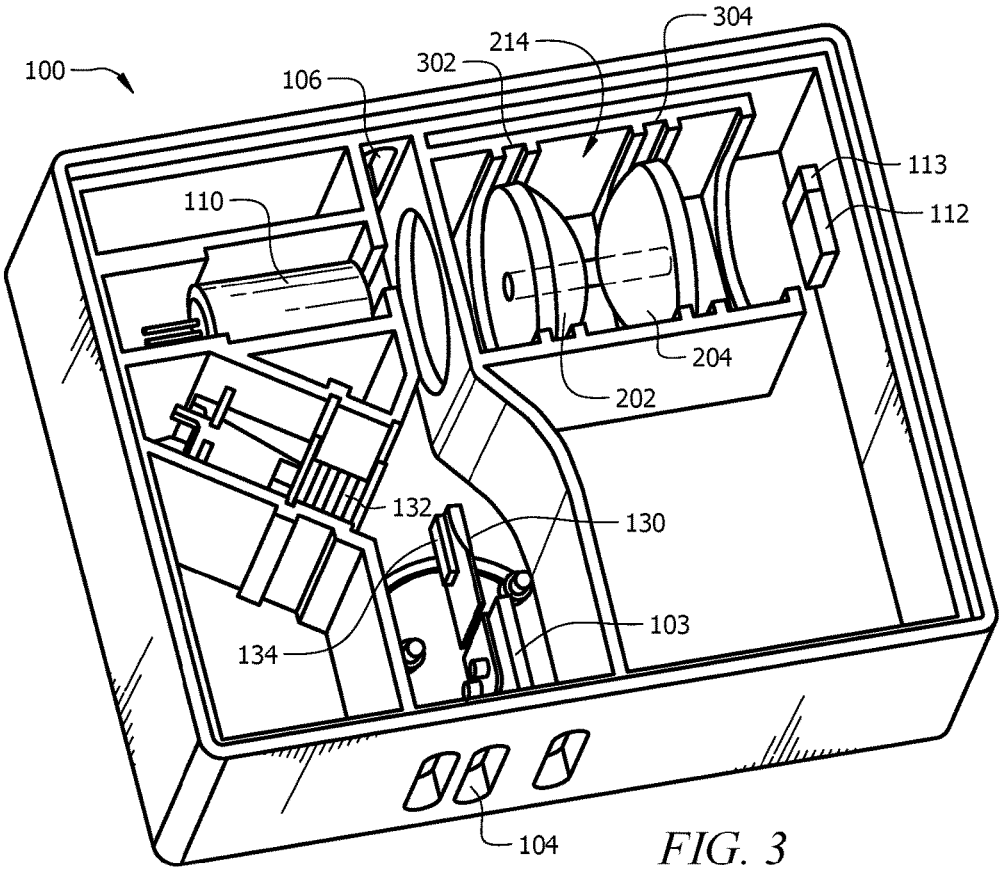


FIG. 3

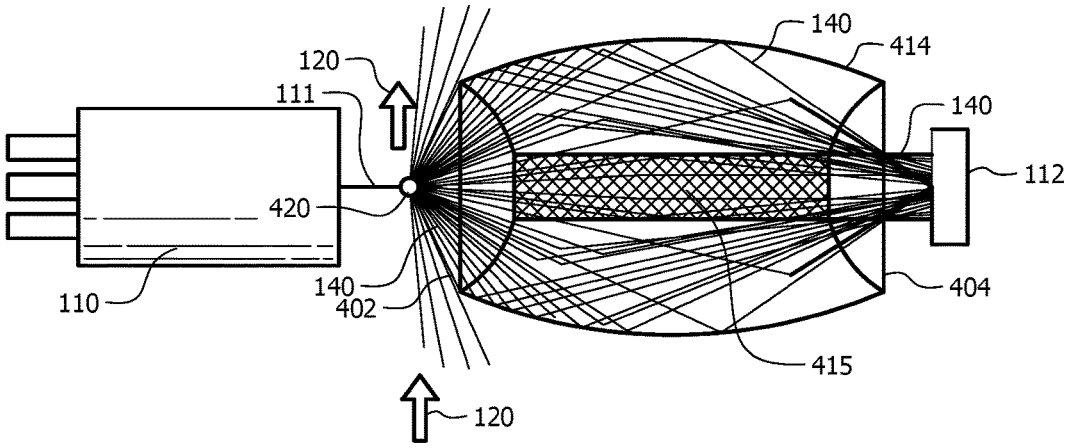

140
414
120
111
140
112
420
140
402
404
110
415
120

FIG. 4A

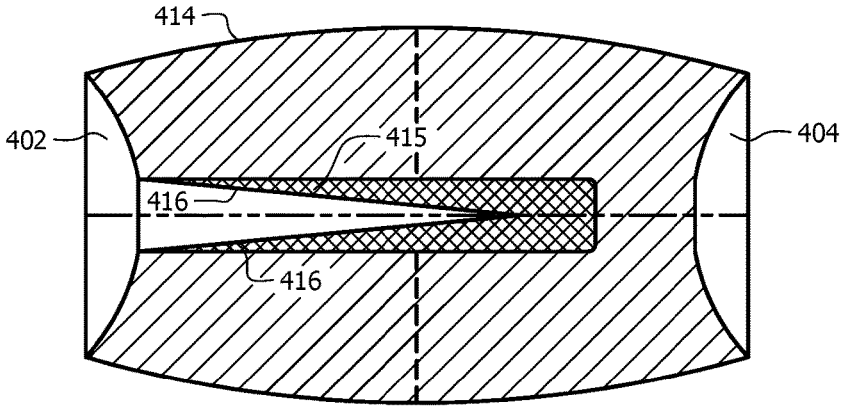

414
402
415
404
416
416

FIG. 4B

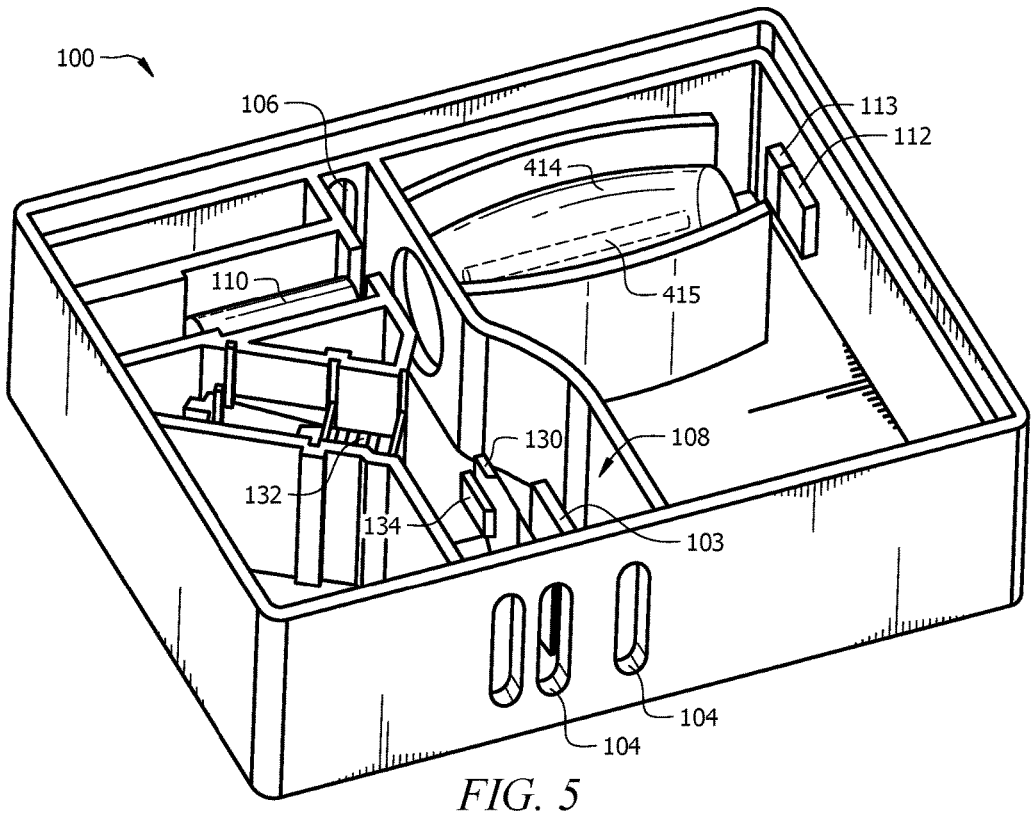


FIG. 5

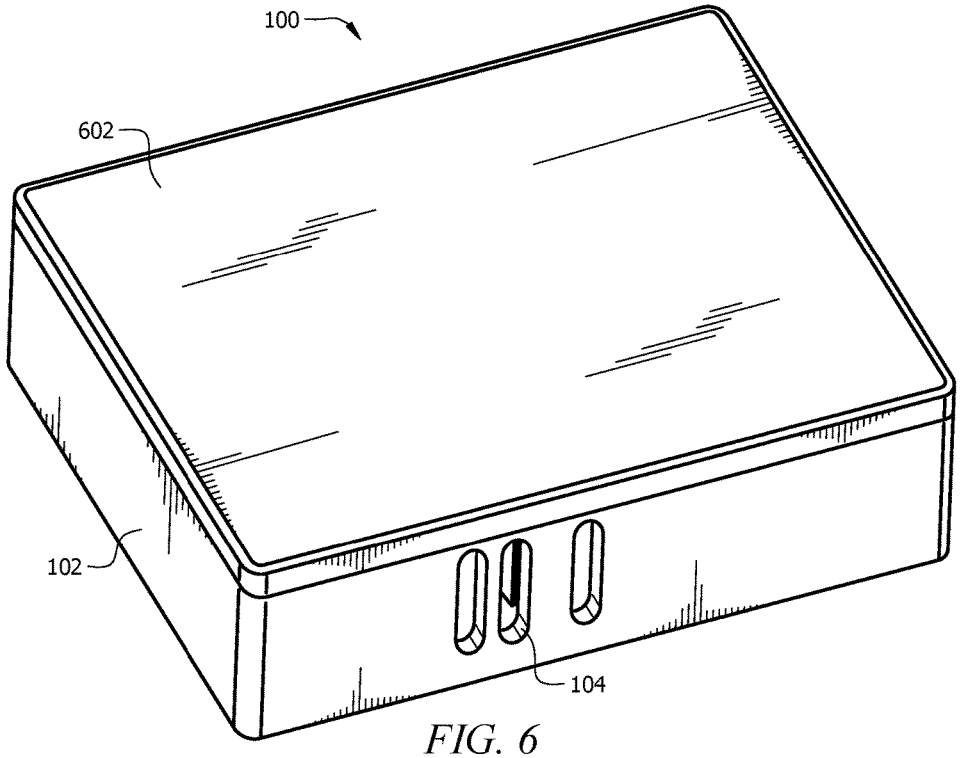


FIG. 6

FORWARD SCATTER IN PARTICULATE MATTER SENSOR

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] Not applicable.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] Not applicable.

REFERENCE TO A MICROFICHE APPENDIX

[0003] Not applicable.

BACKGROUND

[0004] A particulate matter sensor or dust sensor may be used to determine a quality of air, for example in a quality of air that is input to and/or output from an air cleaner. In some industrialized regions, environmental air may have high concentrations of particulate matter of different sizes. If the concentration of such particulate matter is high enough, it may be deleterious to human health. Consumers may wish to purchase and install air cleaners for the residences to improve the quality of air breathed in the home. Such consumer grade air cleaners may desirably be modestly priced and compact in size.

SUMMARY

[0005] In an embodiment, a particulate matter sensor may comprise an airflow channel; a light source configured to pass light through the airflow channel; an airflow generator configured to generate airflow into the airflow channel; a waveguide configured to direct light from the light source after it passes through the airflow channel and scatters off of particulate matter within the airflow channel; a photodiode configured to receive light scattered by the waveguide; and a computing device coupled to the photodiode having a processor and a memory storing instructions which, when executed by the processor, determines a mass concentration of particles in the airflow channel based on an output of the photodiode.

[0006] In an embodiment, a method for determining the concentration of particulate matter within an environment may comprise allowing ambient air to enter a particulate matter sensor; generating an updraft into an airflow channel within the particulate matter sensor; powering a light source within the particulate matter sensor; directing the light source through the airflow channel; receiving, by a waveguide, scattered light that is scattered by particulate matter within the airflow channel; directing, by the waveguide, the scattered light toward a photodiode; and determining a mass concentration of particles in the airflow channel based on an output of the photodiode.

[0007] In an embodiment, a particulate matter sensor may comprise an airflow channel; a laser diode; a housing configured to contain the elements of the sensor; an airflow generator configured to generate airflow into the airflow channel; a photodiode configured to receive light produced by the laser diode; a waveguide positioned between the laser diode and the photodiode, configured to direct light scattered by particulate matter within the airflow channel toward the photodiode; and a computing device coupled to the photodiode having a processor and a memory storing instructions which, when executed by the processor, determines a mass concentration of particles in the airflow channel based on an output of the photodiode.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] For a more complete understanding of the present disclosure, reference is now made to the following brief description, taken in connection with the accompanying drawings and detailed description, wherein like reference numerals represent like parts.

[0009] FIG. **1** illustrates a schematic diagram of a particulate matter sensor according to an embodiment of the disclosure.

[0010] FIGS. **2**A-**2**B illustrate a waveguide for use in a particulate matter sensor according to an embodiment of the disclosure.

[0011] FIG. **3** illustrates a perspective view of a particulate matter sensor according to an embodiment of the disclosure.

[0012] FIGS. **4**A-**4**B illustrate a waveguide for use in a particulate matter sensor according to an embodiment of the disclosure.

[0013] FIG. **5** illustrates a perspective view of a particulate matter sensor according to an embodiment of the disclosure.

[0014] FIG. **6** illustrates an assembled particulate matter sensor according to an embodiment of the disclosure.

DETAILED DESCRIPTION

[0015] It should be understood at the outset that although illustrative implementations of one or more embodiments are illustrated below, the disclosed systems and methods may be implemented using any number of techniques, whether currently known or not yet in existence. The disclosure should in no way be limited to the illustrative implementations, drawings, and techniques illustrated below, but may be modified within the scope of the appended claims along with their full scope of equivalents.

[0016] The following brief definition of terms shall apply throughout the application:

[0017] The term "comprising" means including but not limited to, and should be interpreted in the manner it is typically used in the patent context;

[0018] The phrases "in one embodiment," "according to one embodiment," and the like generally mean that the particular feature, structure, or characteristic following the phrase may be included in at least one embodiment of the present invention, and may be included in more than one embodiment of the present invention (importantly, such phrases do not necessarily refer to the same embodiment);

[0019] If the specification describes something as "exemplary" or an "example," it should be understood that refers to a non-exclusive example;

[0020] The terms "about" or "approximately" or the like, when used with a number, may mean that specific number, or alternatively, a range in proximity to the specific number, as understood by persons of skill in the art field; and

[0021] If the specification states a component or feature "may," "can," "could," "should," "would," "preferably," "possibly," "typically," "optionally," "for example," "often," or "might" (or other such language) be included or have a characteristic, that particular component or feature is not required to be included or to have the characteristic. Such

component or feature may be optionally included in some embodiments, or it may be excluded.

[0022] Embodiments of the disclosure include systems and methods for directing scattered light toward a photodiode within a particulate matter sensor. Typical particulate matter sensors may use a light source and a fan structure to direct airflow through the light source. The scattered light detected by the photodiode may be scattered by particulate matter in an airflow pathway. One or more waveguides may direct the scattered light toward the photodiode.

[0023] Embodiments of the disclosure may relate to forward scattering of light scattered from particulate matter. Greater light scattering occurs in the forward direction and therefore should produce a stronger signal than a typical particulate matter sensor configured to detect scattered light at 90 degrees. However, the forward scatter signal produced is analog, requiring a slightly different signal analysis. This may be accomplished by a computing system within the sensor.

[0024] Utilizing the increased amount of scattered light that can be collected by forward scattering may generate a stronger, enhanced signal generated by the photodiode. The increased intensity may allow for smaller size particles to be detected by the sensor. The sensor may comprise a laser diode (or another similar light source), one or more waveguides (such as an ellipsoidal or spherical mirror), a photodiode detector, and walls and/or baffles within the sensor to ensure that the light is directed toward the intended scatter location.

[0025] FIG. **1** illustrates an exemplary particulate matter sensor **100** comprising a housing **102** with an airflow channel **108** through the housing **102**. The airflow channel **108** may direct airflow **120** through the housing **102** and through a beam **111** from a laser diode **110** (or another light source). The airflow channel **108** is shown as a straight pathway, but in other embodiments, the airflow channel **108** may comprise angles or curves within the sensor housing **102**. The beam **111** may be received by a photodiode **112**, where any light scattered away by the particulate matter in the in the airflow **120** may reduce the beam **111** that is detected by the photodiode **112**. Alternatively, the photodiode **112** may be configured to detect light that is scattered off of the particulate matter within the airflow **120**. The photodiode **112** may comprise or be coupled to a computing device **113** configured to determine a mass concentration of particles in the airflow channel **108** based on an output of the photodiode.

[0026] In some embodiments, the sensor **100** may comprise one or more waveguides **114** configured to amplify the light that is directed toward the photodiode **112**. The waveguide(s) **114** may optionally comprise a light trap **115** located in the path of the beam **111** produced by the laser diode **110**. The laser diode **110** may be placed close to the scatter point (where the beam **111** contacts particulate matter in the airflow **120**) and the light trap **115** to avoid scatter from other regions of the sensor **100**. In some embodiments, the beam **111** produced by the laser diode may be collimated with a diameter of approximately 1 to 2 millimeters. The light trap **115** may comprise a tube shape configured to absorb the beam **111**. In some embodiments, the light trap **115** may comprise a black tube located within the waveguide **114**.

[0027] As shown in FIG. **1**, scattered light **140** may bounce off of particulate matter in the airflow **120**, wherein the scattered light **140** may be directed at an angle to the beam **111**. This scattered light **140** may be captured by the waveguide **114**, and may be directed toward the photodiode **112**. Scattered light **140** may comprise light reflected off of particulate matter within a given angle from the beam **111** that is then directed toward the waveguide **114** and is scattered forward by the waveguide **114**.

[0028] It may be desired for the photodiode **112** to only receive the light scattered off of the particulate matter. For this reason, the beam **111** produced by the laser diode **110** may be trapped and/or blocked from reaching the photodiode **112**. As an example, a light trap **115** may be placed within the waveguide(s) **114**, wherein the light trap **115** may contain the beam **111** and prevent it from reaching the photodiode **112**. Additionally, the light trap **115** may be configured to prevent the beam **111** from reflecting back into the airflow channel **108**.

[0029] The sensor **100** may comprise an airflow generator **130** configured to provide airflow **120** through the airflow channel **108**. The airflow generator **130** may draw airflow **120** into the housing **102** via an inlet **104**, where the airflow **120** may pass through the beam **111** of the laser diode **110**, and may be directed out of the housing **102** via an outlet **106**. The airflow generator **130** may comprise a mechanical airflow generator, such as a fan, a blade, and/or a flipper. The airflow generator **130** may comprise a conduction airflow generator. The airflow generator **130** may comprise any element that is configured to produce airflow through the airflow channel **108**. As shown in FIG. **1**, the airflow generator **130** may be located within the housing **102** of the sensor **100**. Alternatively, the airflow generator **130** may be located external to the housing **102** of the sensor **100**.

[0030] FIGS. **2**A-**2**B illustrate exemplary embodiments of a waveguide **214** which may be similar to the waveguide(s) **114** described above. In the embodiment shown in FIGS. **2**A-**2**B, the waveguide **214** may comprise a first condensing lens **202** and a second condensing lens **204**. The first condensing lens **202** may be configured to receive scattered light **140** that is scattered off of particulate matter **220** in the airflow **120**. The scattered light **140** received by the first condensing lens **202** may be within a range of angles indicated by the area **240**. The scattered light **140** received by the first condensing lens **202** may be between approximately 10 to 40 degrees from the beam **111** produced by the laser diode **110**. In some embodiments, the scattered light **140** received by the waveguide **214** may be at an angle greater than 5 degrees from the beam **111**. In some embodiments, the scattered light **140** received by the waveguide **214** may be at an angle less than 90 degrees from the beam **111**.

[0031] The scattered light **140** received by the first condensing lens **202** may be directed to the second condensing lens **204**, where the second condensing lens **204** may direct the scattered light **140** to the photodiode **112**. Therefore, the photodiode **112** may measure light that is scattered off of particulate matter **220** within the airflow **120**.

[0032] The waveguide **214** may also comprise a light trap **215** located within the first condensing lens **202**. The light trap **215** may be configured to prevent the beam **111** produced by the laser diode **110** from reaching the photodiode **112**. In some embodiments, the light trap **215** may comprise one or more angled walls **216** configured to prevent the beam **111** from reflecting back into the pathway of the airflow **120**.

[0033] FIG. **2**B illustrates a detailed view of a waveguide **214**. In some embodiments, the light trap **215** may extend through both the first condensing lens **202** and the second condensing lens **204**. In some embodiments, the light trap **215** may comprise angled walls **216** forming a conical shape within the light trap **215**. The conical shape may efficiently trap the beam **111** produced by the laser diode **112**. In some embodiments, the interior angled walls **216** may comprise a light absorbing coating or material.

[0034] FIG. **3** illustrates a perspective view of the sensor **100** with the top of the housing **102** removed, where the waveguide **214** and light trap **215** are incorporated into the sensor **100**. The waveguide **214** may be located between the laser diode **110** and the photo diode **112**. The waveguide **214** may be at least partially contained by walls within the housing **102**. In some embodiments, grooves **302** and **304** may be configured to hold the lenses **202** and **204** in place within the housing **102**. The grooves **302** and **304** as well as other walls within the housing **102** may be structured to reduce the contact area between the housing **102** and the active area on the surfaces of the waveguide **214**. In other words, the housing **102** may be designed to hold the waveguide **214** in place without interfering with the light that is scattered through the waveguides **214**.

[0035] As described above, the airflow channel **108** may be formed by walls within the housing **102**. The inlet **104** may comprise one or more openings in the housing **102**. The outlet **106** may comprise one or more openings in the housing **102**.

[0036] Additionally, the sensor **100** may comprise a flipper **130** that may be controlled by a coil **132** located near the flipper **130**. The flipper **130** may be moved back and forth on an axis, pulling airflow into the airflow channel **108** via the inlet **104**. The airflow **120** may be forced through the airflow channel **108** toward the outlet **106**, passing through the beam **111**. The airflow channel **108** is shown as a straight pathway, but in other embodiments, the airflow channel **108** may comprise angles or curves within the sensor housing **102**.

[0037] The coil **132** may be located within the housing **102**, adjacent to the flipper **130**. The flipper **130** may be located within the housing **102** near the inlet **104**. In some embodiments, the flipper **130** may be located anywhere within the airflow channel **108**. In some embodiments, the coil **132** may be located on one side of the airflow channel **108** while the additional waveguide **214** may be located on the opposite side of the airflow channel **108**. This may prevent the coil **132** from interfering with the waveguides **114** and/or photodiode **112**. Additionally, the coil **132** may be positioned such that the size of the housing **102** may be as small as possible while containing all of the elements described.

[0038] The flipper **130** may be attached to a wall or extended portion **103** of the housing **102**. The flipper **130** may comprise a magnet **134** attached to and/or incorporated into the flipper **130**. The flipper **130** may be controlled by a magnetic force generated by the electric coil **132**. The coil **132** may generate alternating electric fields to push and pull the flipper **130** by applying attractive and repulsive forces to the magnet **134**. One end of the flipper **130** may be secured to the housing **102**, and the magnet **134** may be located on the unattached portion of the flipper **130**.

[0039] In some embodiments, the flipper **130** can be biased in one direction by a spring or other biasing member (e.g., gravity, etc.). The coil **132** can then generate an attractive or repulsive force to move the flipper **130** against the bias force. The coil **132** can then cease generation of the attractive or repulsive force to allow the bias member to return the flipper **130** to the resting position. Repetition of this cycle can cause the flipper **130** to move back and forth within the airflow channel **108**.

[0040] The movement of the flipper **130** may generate airflow **120** drawing it in through the inlet **104**. The particulate matter in the airflow **120** may be detected via the laser diode **110** and the photodiode **112**. The coil **132** may be configured to produce an electric field at a particular frequency to drive the magnet **134**, and therefore the flipper **130**, to swing back and forth. In some embodiments, the frequency produced by the coil may be a square wave at approximately 3.3V. In some embodiments, the frequency of the coil **132** may be controlled based on the determined airflow rate through the sensor **100**. In some embodiments, the determined airflow rate can be determined using a correlation between the flipper movement speed and a flow rate, which can be determined using an equation, a look-up table, or another representation of the correlation. In the embodiment shown, the coil **132** may be located at an angle to the flipper **130**, where the angle and position of the coil **132** may be adjusted and chosen based on the interaction between the coil **132** and the flipper **130**, to provide the strongest and most reliable effect from the coil **132** on the flipper **130**.

[0041] FIGS. **4**A-**4**B illustrate an exemplary embodiment of a waveguide **414** which may be similar to the waveguide (s) **114** described above. In the embodiment shown in FIGS. **4**A-**4**B, the waveguide **414** may comprise an ellipse mirror comprising two flat surfaces, wherein the flat surfaces function as an inlet **402** and outlet **404** of the waveguide **414**.

[0042] The inlet **402** may be configured to receive scattered light **140** that is scattered off of particulate matter **420** in the airflow **120**. The scattered light **140** received by the inlet **402** may be within a range of angles from the beam **111**. The scattered light **140** received by the inlet **402** may be between approximately 10 to 40 degrees from the beam **111** produced by the laser diode **110**. In some embodiments, the scattered light **140** received by the waveguide **414** may be at an angle greater than 10 degrees from the beam **111**. The scattered light **140** received by the inlet **402** may be directed through the ellipse mirror toward the outlet **404**, where the outlet **404** may direct the scattered light **140** to the photodiode **112**. Therefore, the photodiode **112** may measure light that is scattered off of particulate matter **420** within the airflow **120**.

[0043] The waveguide **414** may also comprise a light trap **415** located within the ellipse mirror. The light trap **415** may be configured to prevent the beam **111** produced by the laser diode **110** from reaching the photodiode **112**. In some embodiments, the light trap **415** may comprise one or more angled walls **416** configured to prevent the beam **111** from reflecting back into the pathway of the airflow **120**.

[0044] FIG. **4**B illustrates a detailed view of the waveguide **414**. In some embodiments, the light trap **415** may extend through only a portion of the waveguide **414**, while in other embodiments, the light trap **415** may extend through the entire waveguide **414**. In some embodiments, the light trap **415** may comprise angled walls **416** forming a conical shape within the light trap **415**. The conical shape may efficiently trap the beam **111** produced by the laser diode

110. In some embodiments, the interior angled walls **416** may comprise a light absorbing coating or material.

[0045] The embodiment shown in FIGS. **4**A-**4**B uses an ellipse mirror as the waveguide **414**. However, in other embodiments, additional lenses may be used with the ellipse mirror and positioned around the waveguide **514** to collect even more scattered light from the region of interaction between the beam **111** and particulate matter.

[0046] FIG. **5** illustrates a perspective view of the sensor **100** with the top of the housing **102** removed, where the waveguide **414** and light trap **415** are incorporated into the sensor **100**. The waveguide **414** may be located between the laser diode **110** and the photodiode **112**. The waveguide **414** may be at least partially contained by walls within the housing **102**. The walls within the housing **102** may be structured to reduce the contact area between the housing **102** and the active area on the surfaces of the waveguide **414**. In other words, the housing **102** may be designed to hold the waveguide **414** in place without interfering with the light that is scattered through the waveguides **414**.

[0047] As described above, the airflow channel **108** may be formed by walls within the housing **102**. The inlet **104** may comprise one or more openings in the housing **102**. The outlet **106** may comprise one or more openings in the housing **102**. The airflow generator of the sensor **100** may comprise a flipper **130**, as described above in FIG. **3**.

[0048] FIG. **6** illustrates an assembled particulate matter sensor **100**, wherein the housing **102** may comprise a top portion **602** that attaches to the housing **102** and covers the internal elements of the sensor **100**.

[0049] In a first embodiment, a particulate matter sensor may comprise an airflow channel; a light source configured to pass light through the airflow channel; an airflow generator configured to generate airflow into the airflow channel; a waveguide configured to direct light from the light source after it passes through the airflow channel and scatters off of particulate matter within the airflow channel; a photodiode configured to receive light scattered by the waveguide; and a computing device coupled to the photodiode having a processor and a memory storing instructions which, when executed by the processor, determines a mass concentration of particles in the airflow channel based on an output of the photodiode.

[0050] A second embodiment can include the particulate matter sensor of the first embodiment, wherein the waveguide directs light that scatters between approximately 10 and 40 degrees from a beam produced by the light source.

[0051] A third embodiment can include the particulate matter sensor of the first or second embodiments, wherein the waveguide directs light that scatters at least 5 degrees from the beam produced by the light source.

[0052] A fourth embodiment can include the particulate matter sensor of any of the first to third embodiments, wherein the waveguide directs light that scatters less than 90 degrees from the beam produced by the light source.

[0053] A fifth embodiment can include the particulate matter sensor of any of the first to fourth embodiments, wherein light scattered by the particulate matter is forward scattered by the waveguide toward the photodiode.

[0054] A sixth embodiment can include the particulate matter sensor of any of the first to fifth embodiments, further comprising a light trap configured to prevent the beam produced by the light source from reaching the photodiode.

[0055] A seventh embodiment can include the particulate matter sensor of the sixth embodiment, wherein the light trap is further configured to prevent the beam from reflecting back into the airflow channel.

[0056] An eighth embodiment can include the particulate matter sensor of any of the first to seventh embodiments, wherein the sensor is a dust sensor.

[0057] A ninth embodiment can include the particulate matter sensor of any of the first to eighth embodiments, wherein the light source is a laser diode.

[0058] In a tenth embodiment, a method for determining the concentration of particulate matter within an environment may comprise allowing ambient air to enter a particulate matter sensor; generating an updraft into an airflow channel within the particulate matter sensor; powering a light source within the particulate matter sensor; directing the light source through the airflow channel; receiving, by a waveguide, scattered light that is scattered by particulate matter within the airflow channel; directing, by the waveguide, the scattered light toward a photodiode; and determining a mass concentration of particles in the airflow channel based on an output of the photodiode.

[0059] An eleventh embodiment can include the method of the tenth embodiment, wherein the light source comprises a laser diode.

[0060] A twelfth embodiment can include the method of the tenth or eleventh embodiments, further comprising directing scattered light within a range of angles from the light source toward the photodiode.

[0061] A thirteenth embodiment can include the method of any of the tenth to twelfth embodiments, further comprising preventing a beam produced by the light source from reaching the photodiode.

[0062] A fourteenth embodiment can include the method of any of the tenth to thirteenth embodiments, further comprising preventing the light source from directly reaching the photodiode by a light trap located within the waveguide.

[0063] A fifteenth embodiment can include the method of the fourteenth embodiment, wherein determining the mass concentration of particles in the airflow channel is completed by a computing device connected to the photodiode.

[0064] In a sixteenth embodiment, a particulate matter sensor may comprise an airflow channel; a laser diode; a housing configured to contain the elements of the sensor; an airflow generator configured to generate airflow into the airflow channel; a photodiode configured to receive light produced by the laser diode; a waveguide positioned between the laser diode and the photodiode, configured to direct light scattered by particulate matter within the airflow channel toward the photodiode; and a computing device coupled to the photodiode having a processor and a memory storing instructions which, when executed by the processor, determines a mass concentration of particles in the airflow channel based on an output of the photodiode.

[0065] A seventeenth embodiment can include the particulate matter sensor of the sixteenth embodiment, wherein the waveguide directs light that scatters less than 90 degrees from the beam produced by the light source.

[0066] An eighteenth embodiment can include the particulate matter sensor of the sixteenth or seventeenth embodiments, further comprising a light trap configured to prevent the beam produced by the light source from reaching the photodiode.

[0067] A nineteenth embodiment can include the particulate matter sensor of the eighteenth embodiment, wherein the light trap is further configured to prevent the beam from reflecting back into the airflow channel.

[0068] A twentieth embodiment can include the particulate matter sensor of the eighteenth or nineteenth embodiments, wherein the light trap comprises one or more angled surfaces.

[0069] While various embodiments in accordance with the principles disclosed herein have been shown and described above, modifications thereof may be made by one skilled in the art without departing from the spirit and the teachings of the disclosure. The embodiments described herein are representative only and are not intended to be limiting. Many variations, combinations, and modifications are possible and are within the scope of the disclosure. Alternative embodiments that result from combining, integrating, and/or omitting features of the embodiment(s) are also within the scope of the disclosure. Accordingly, the scope of protection is not limited by the description set out above, but is defined by the claims which follow, that scope including all equivalents of the subject matter of the claims. Each and every claim is incorporated as further disclosure into the specification and the claims are embodiment(s) of the present invention(s). Furthermore, any advantages and features described above may relate to specific embodiments, but shall not limit the application of such issued claims to processes and structures accomplishing any or all of the above advantages or having any or all of the above features.

[0070] Additionally, the section headings used herein are provided for consistency with the suggestions under 37 C.F.R. 1.77 or to otherwise provide organizational cues. These headings shall not limit or characterize the invention (s) set out in any claims that may issue from this disclosure. Specifically and by way of example, although the headings might refer to a "Field," the claims should not be limited by the language chosen under this heading to describe the so-called field. Further, a description of a technology in the "Background" is not to be construed as an admission that certain technology is prior art to any invention(s) in this disclosure. Neither is the "Summary" to be considered as a limiting characterization of the invention(s) set forth in issued claims. Furthermore, any reference in this disclosure to "invention" in the singular should not be used to argue that there is only a single point of novelty in this disclosure. Multiple inventions may be set forth according to the limitations of the multiple claims issuing from this disclosure, and such claims accordingly define the invention(s), and their equivalents, that are protected thereby. In all instances, the scope of the claims shall be considered on their own merits in light of this disclosure, but should not be constrained by the headings set forth herein.

[0071] Use of broader terms such as "comprises," "includes," and "having" should be understood to provide support for narrower terms such as "consisting of," "consisting essentially of," and "comprised substantially of." Use of the terms "optionally," "may," "might," "possibly," and the like with respect to any element of an embodiment means that the element is not required, or alternatively, the element is required, both alternatives being within the scope of the embodiment(s). Also, references to examples are merely provided for illustrative purposes, and are not intended to be exclusive.

[0072] While several embodiments have been provided in the present disclosure, it should be understood that the disclosed systems and methods may be embodied in many other specific forms without departing from the spirit or scope of the present disclosure. The present examples are to be considered as illustrative and not restrictive, and the intention is not to be limited to the details given herein. For example, the various elements or components may be combined or integrated in another system or certain features may be omitted or not implemented.

[0073] Also, techniques, systems, subsystems, and methods described and illustrated in the various embodiments as discrete or separate may be combined or integrated with other systems, modules, techniques, or methods without departing from the scope of the present disclosure. Other items shown or discussed as directly coupled or communicating with each other may be indirectly coupled or communicating through some interface, device, or intermediate component, whether electrically, mechanically, or otherwise. Other examples of changes, substitutions, and alterations are ascertainable by one skilled in the art and could be made without departing from the spirit and scope disclosed herein.

1. A particulate matter sensor comprising:

an airflow channel;

a light source configured to pass light through the airflow channel;

an airflow generator configured to generate airflow into the airflow channel;

a waveguide configured to direct light from the light source after it passes through the airflow channel and scatters off particulate matter within the airflow channel, wherein the waveguide includes a first condensing lens and a second condensing lens, wherein the first condensing lens is configured to receive scattered light that is scattered off the particulate matter within the airflow channel, and is configured to direct the received scattered light to the second condensing lens, and the second condensing lens is configured to direct the scattered light to a photodiode;

the photodiode is configured to receive the scattered light from the second condensing lens; and

a computing device coupled to the photodiode having a processor and a memory storing instructions which, when executed by the processor, determines a mass concentration of particles in the airflow channel based on an output of the photodiode.

2. The particulate matter sensor of claim **1**, wherein the first condensing lens of the waveguide directs light that scatters between approximately 10 and 40 degrees from a beam produced by the light source.

3. The particulate matter sensor of claim **1**, wherein the first condensing lens of the waveguide directs light that scatters at least 5 degrees from the beam produced by the light source.

4. The particulate matter sensor of claim **1**, wherein the first condensing lens of the waveguide directs light that scatters less than 90 degrees from the beam produced by the light source.

5. The particulate matter sensor of claim **1**, wherein light scattered by the particulate matter is forward scattered by the waveguide toward the photodiode.

6. The particulate matter sensor of claim **1**, further comprising a light trap configured to prevent the beam produced by the light source from reaching the photodiode.

7. The particulate matter sensor of claim **6**, wherein the light trap is further configured to prevent the beam from reflecting back into the airflow channel.

8. The particulate matter sensor of claim **1**, wherein the first condensing lens includes a curved output surface and the second condensing lens includes a curved input surface, wherein the curved output surface of the first condensing lens faces the curved input surface of the second condensing lens.

9. The particulate matter sensor of claim **1**, wherein the light source is a laser diode.

10. A method for determining the concentration of particulate matter within an environment, the method comprising:

allowing ambient air to enter a particulate matter sensor;

generating an updraft into an airflow channel within the particulate matter sensor;

powering a light source within the particulate matter sensor to produce a light beam;

directing the light beam through the airflow channel;

receiving, by a first condensing lens of a waveguide, scattered light that is scattered by particulate matter within the airflow channel;

directing, by the first condensing lens of the waveguide, the scattered light to a second condensing lens of the waveguide;

directing, by the second condensing lens of the waveguide, the scattered light toward a photodiode; and

determining a mass concentration of particles in the airflow channel based on an output of the photodiode.

11. The method of claim **10**, wherein the light source comprises a laser diode.

12. The method of claim **10**, further comprising directing scattered light within a range of angles from the light source toward the photodiode.

13. The method of claim **10**, further comprising preventing the light beam produced by the light source from directly reaching the photodiode.

14. The method of claim **10**, further comprising preventing the light beam from directly reaching the photodiode by a light trap located within the waveguide.

15. The method of claim **10**, wherein determining the mass concentration of particles in the airflow channel is completed by a computing device operatively coupled to the photodiode.

16. A particulate matter sensor comprising:

an airflow channel;

a laser diode;

a housing configured to contain the elements of the sensor;

an airflow generator configured to generate airflow into the airflow channel;

a photodiode configured to receive light produced by the laser diode;

a waveguide positioned between the laser diode and the photodiode, configured to direct light scattered by particulate matter within the airflow channel toward the photodiode;

wherein the waveguide includes an ellipse mirror, the ellipse mirror having an inlet that is configured to receive light scattered by the particulate matter within the airflow channel, and the ellipse mirror is configured to direct at least some of the received scattered light toward the photodiode; and

a computing device coupled to the photodiode having a processor and a memory storing instructions which, when executed by the processor, determines a mass concentration of particles in the airflow channel based on an output of the photodiode.

17. The particulate matter sensor of claim **16**, wherein the ellipse mirror of the waveguide directs light that scatters less than 90 degrees from the beam produced by the light source.

18. The particulate matter sensor of claim **16**, further comprising a light trap configured to prevent the beam produced by the light source from directly reaching the photodiode.

19. The particulate matter sensor of claim **18**, wherein the light trap is further configured to prevent the beam from reflecting back into the airflow channel.

20. The particulate matter sensor of claim **18**, wherein the light trap comprises one or more angled surfaces.

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