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(54) FILTER ASSEMBLY FOR PROVIDING ADJUSTABLE SPECTRAL CAPABILITIES IN A BROADBAND INSPECTION SYSTEM

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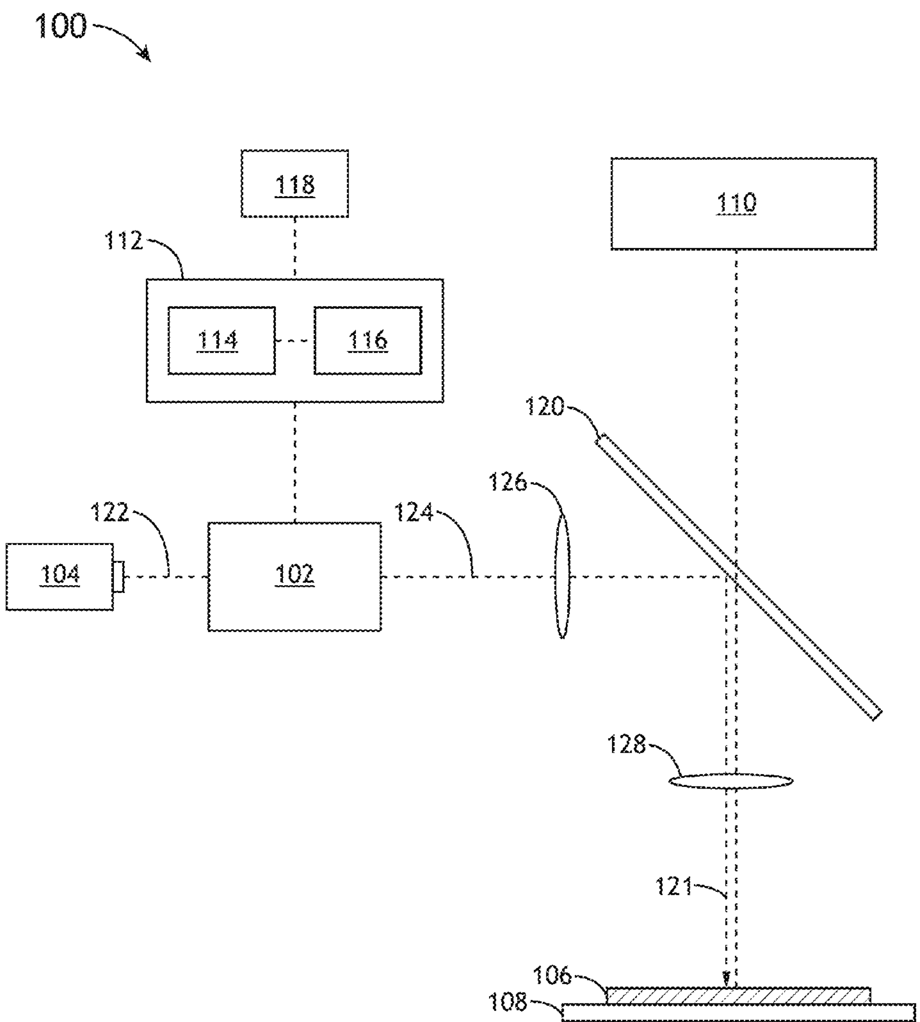
(57) **ABSTRACT**

A system which may be used to which may be used to increase the number of available spectrum bands in an inspection system is provided. The system may include an illumination source configured to emit broadband illumination. The system may also include a filter assembly including two or more filter units. The two or more filter units may include two or more filters with one or more varying filtering characteristics. The system may also include two or more motors configured to selectively actuate selected filters of the filter units into the beam of illumination. Using the system, the number of available spectrum bands to be used in an inspection system may be increased.



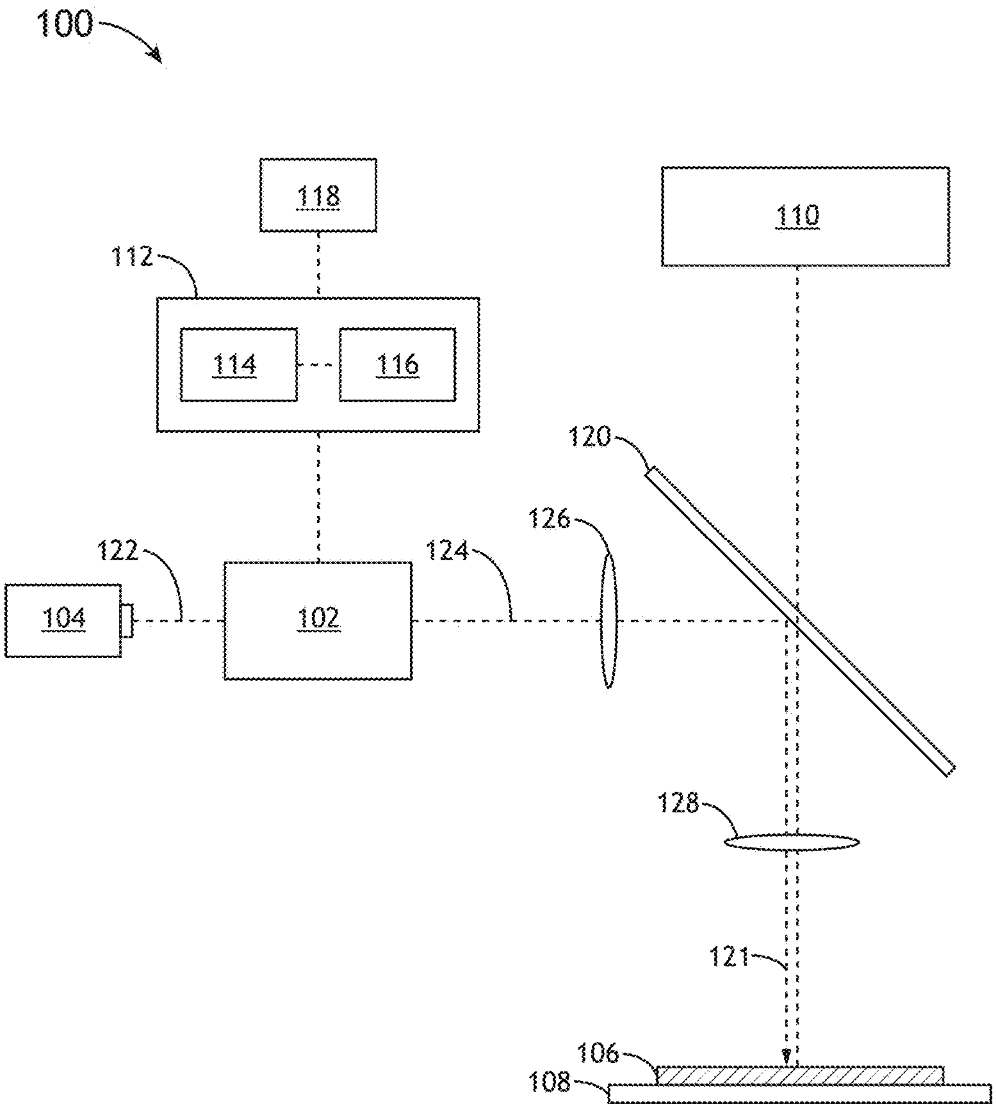


FIG.1A

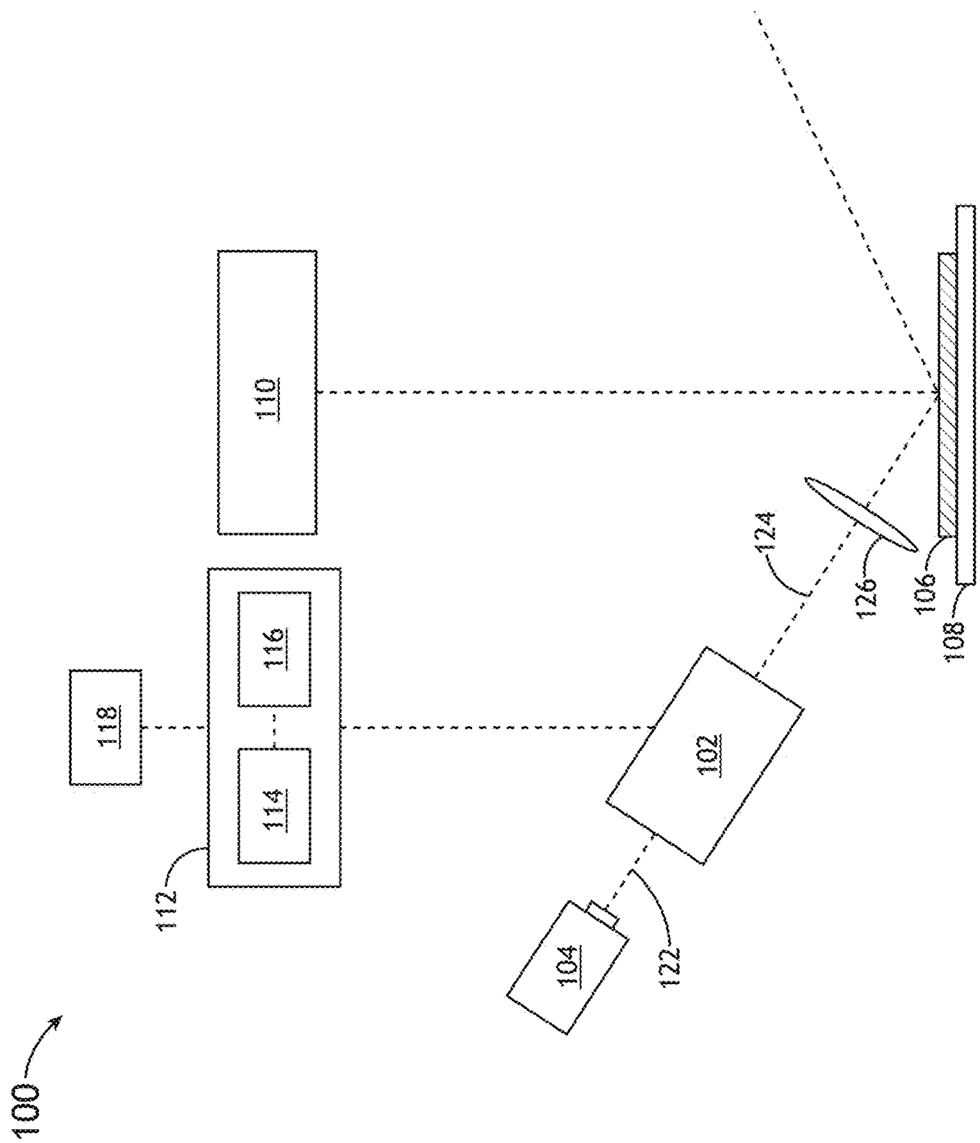


FIG. 1B

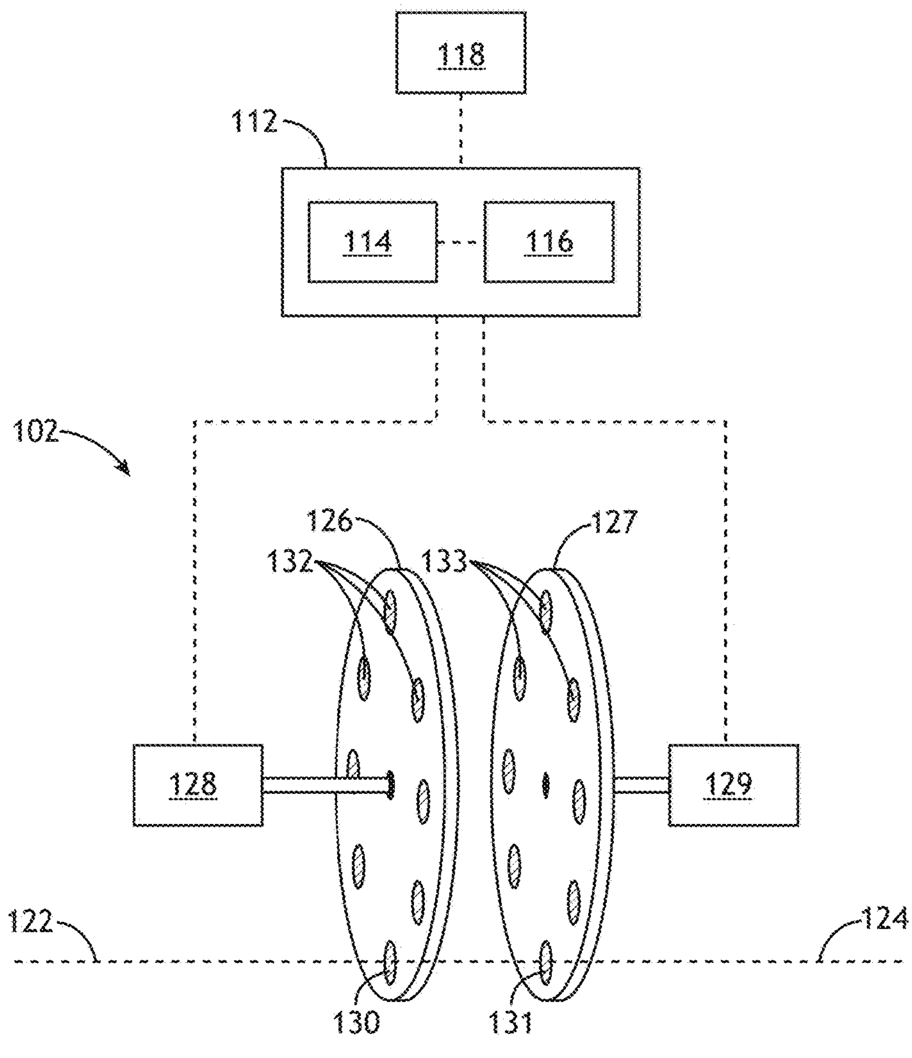


FIG.1C

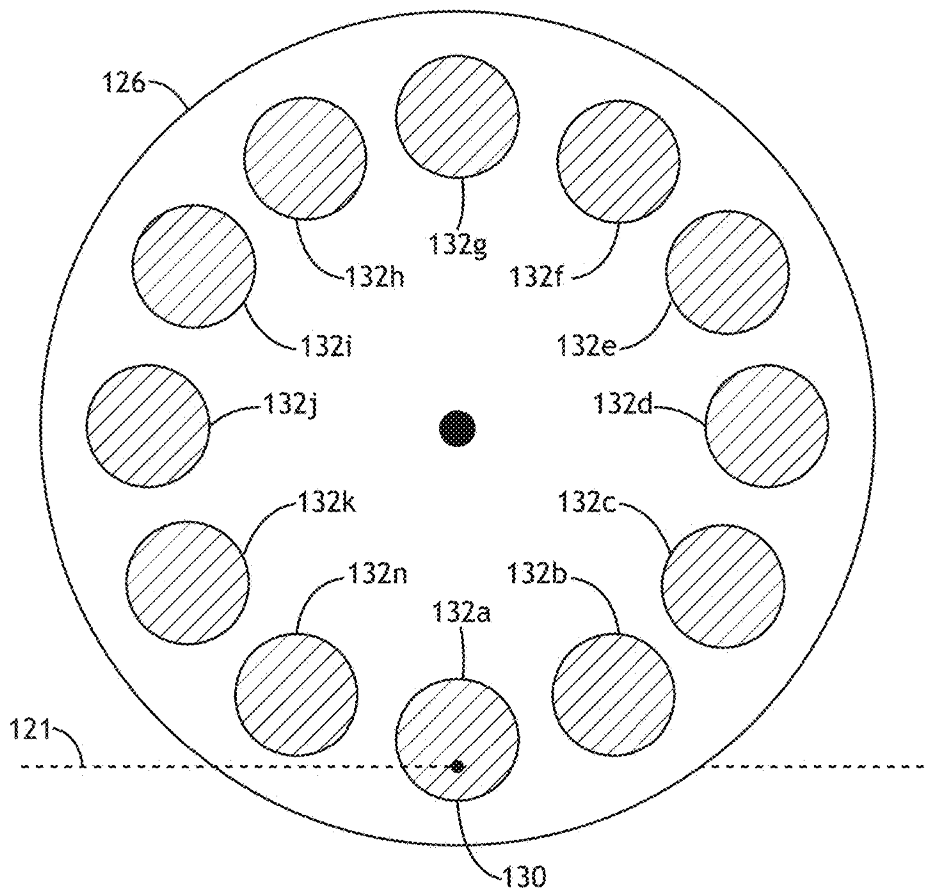

126
132g
132h
132f
132i
132e
132j
132d
132k
132c
132n
132b
132a
121
130

FIG. 1D

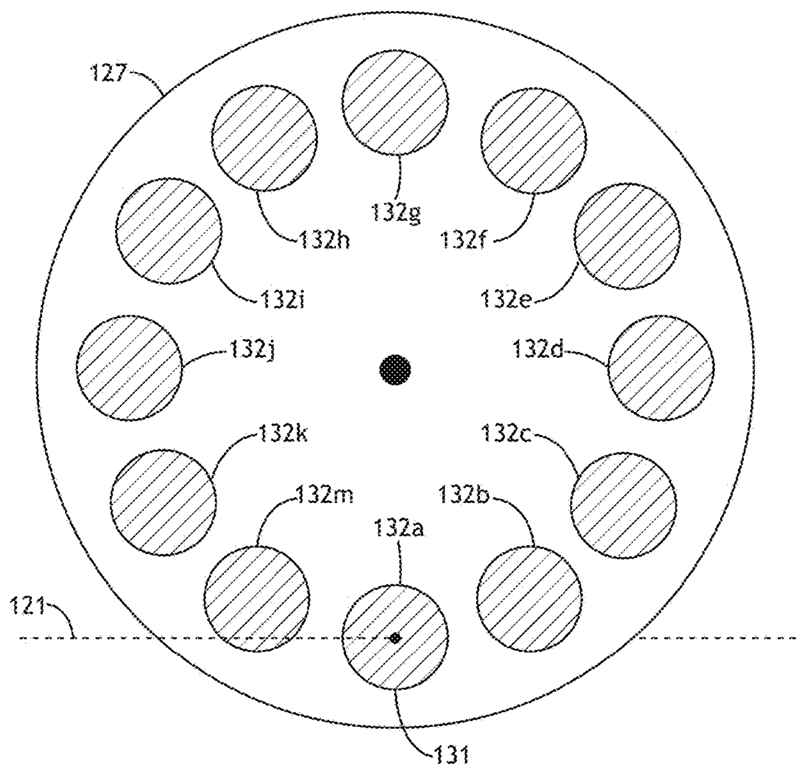

127
132g
132h
132f
132i
132e
132j
132d
132k
132c
132m
132b
132a
121
131

FIG. 1E

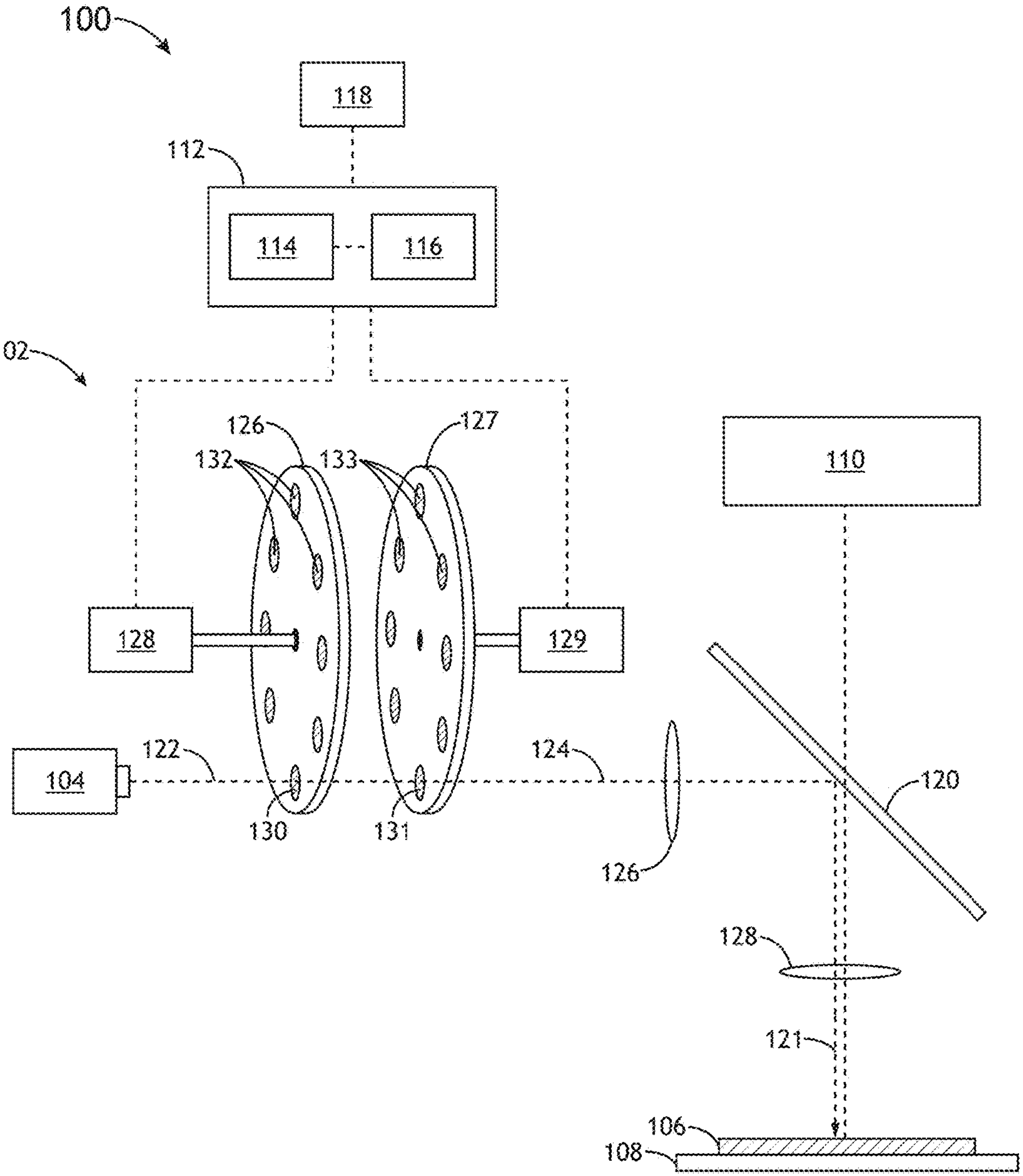

100
118
112
114
116
102
126
127
132
133
110
128
129
104
122
124
120
130
131
126
128
121
106
108

FIG.1F

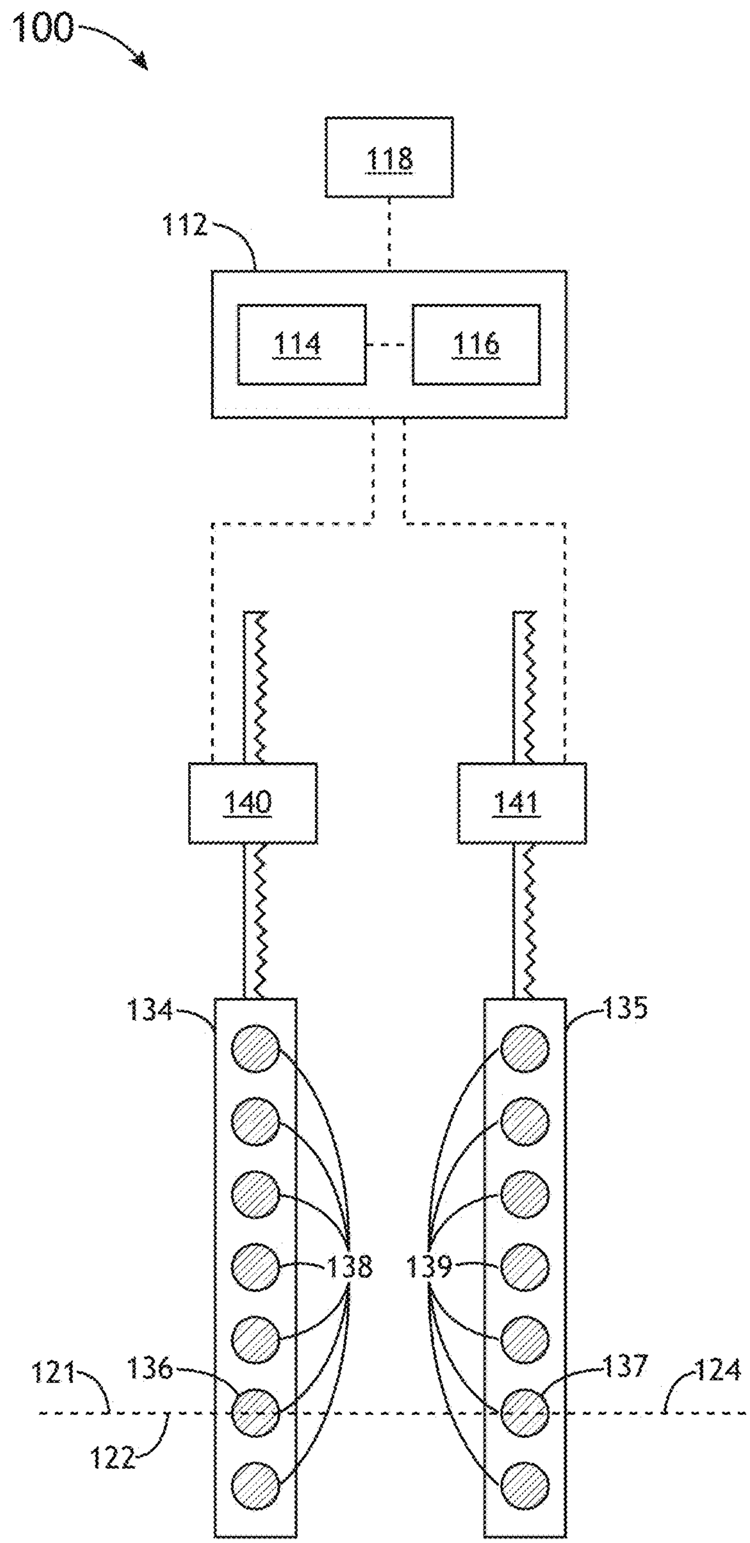


FIG. 1G

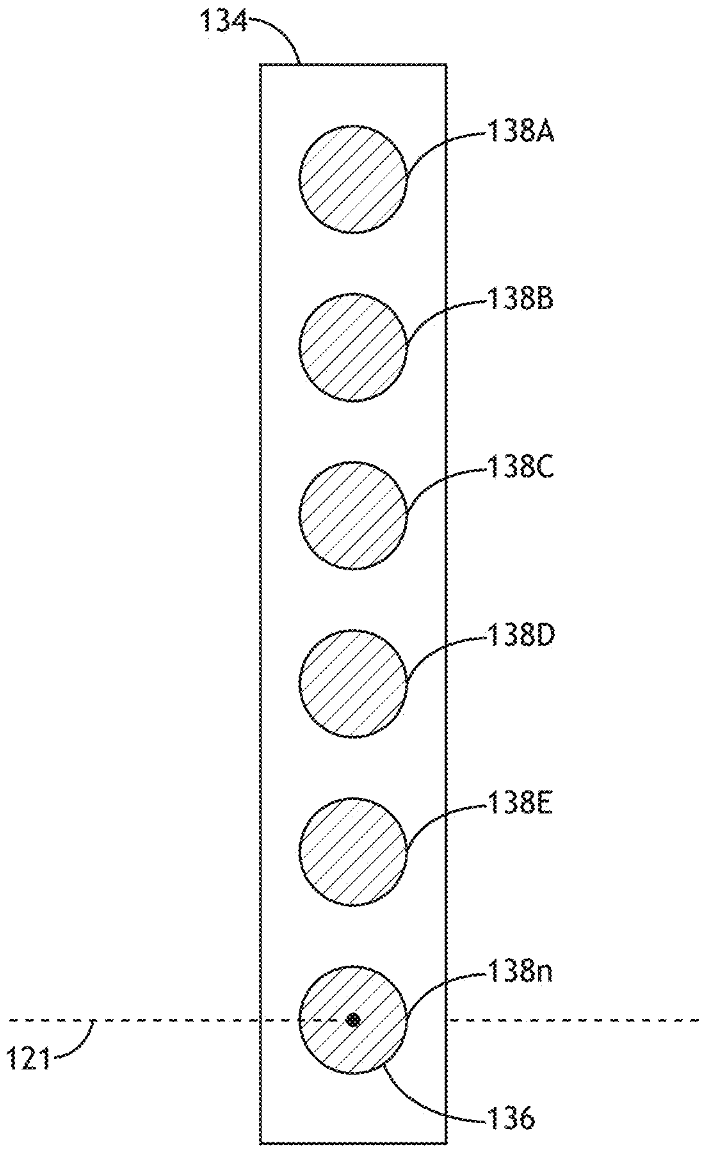


FIG. 1H

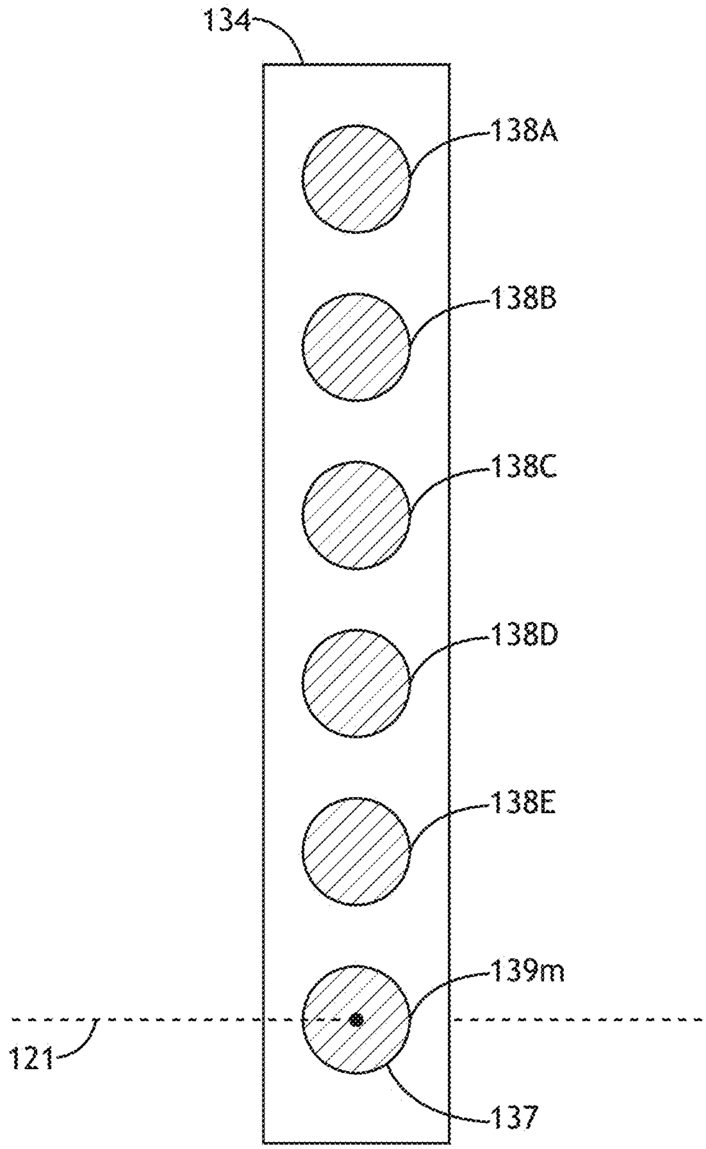


FIG.1I

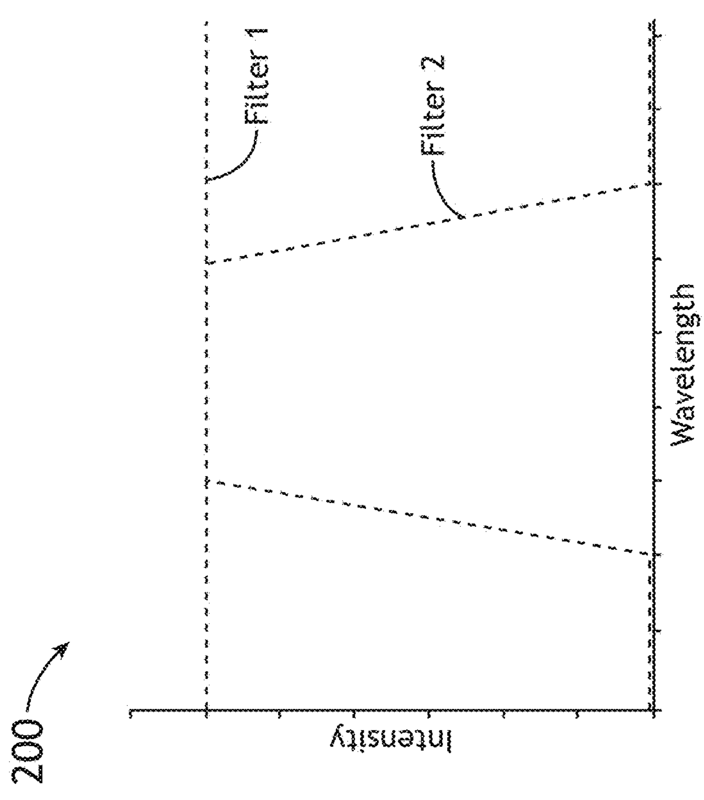

200
Intensity
Wavelength
Filter 1
Filter 2

FIG.2A

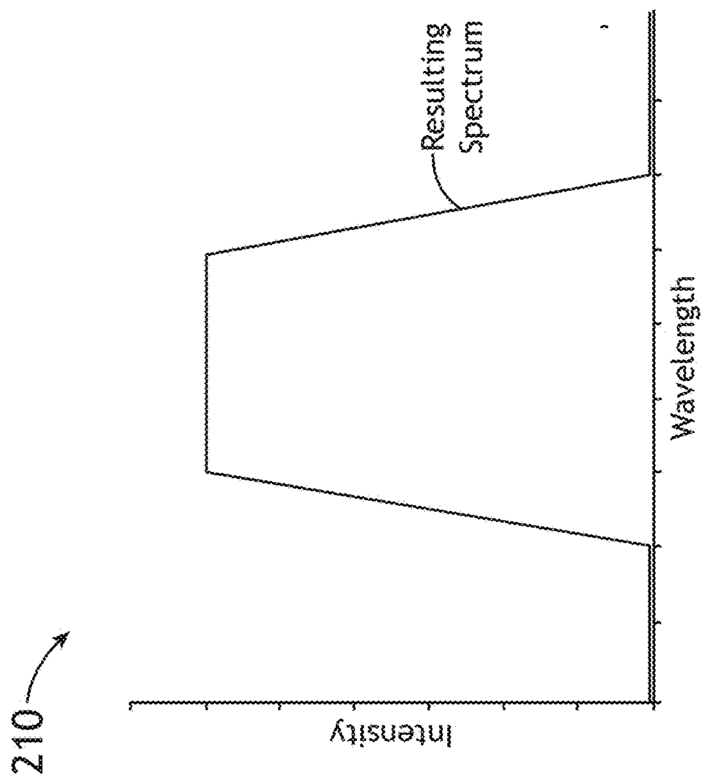

210
Intensity
Wavelength
Resulting Spectrum

FIG.2B

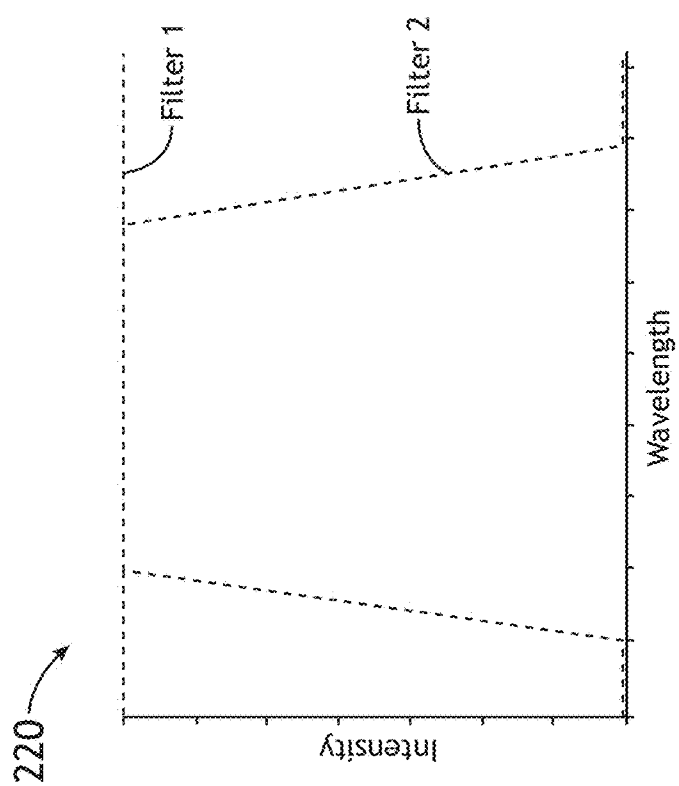

220
Filter 1
Filter 2
Intensity
Wavelength

FIG. 2C

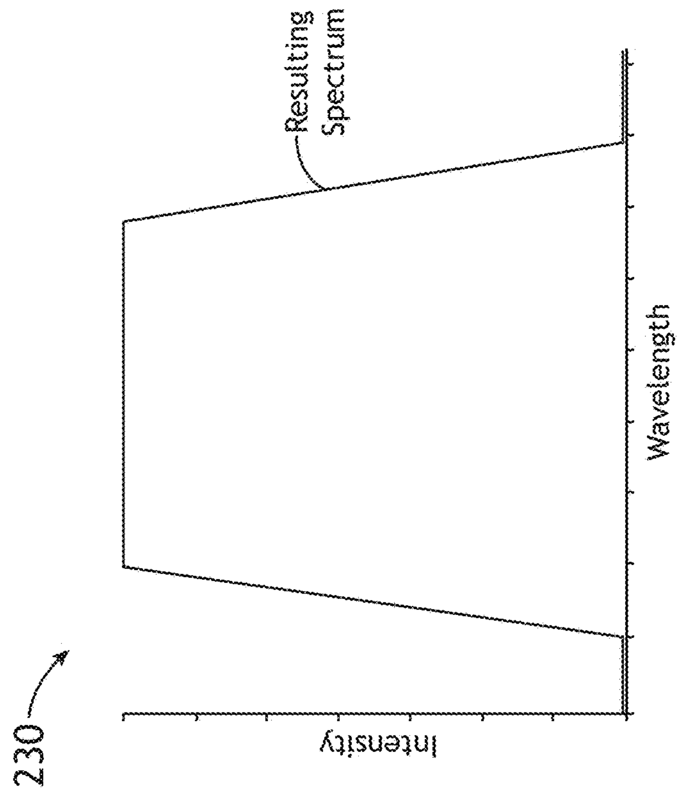

230
Resulting Spectrum
Intensity
Wavelength

FIG. 2D

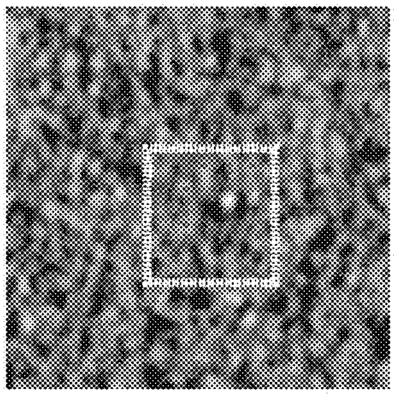


FIG.3A

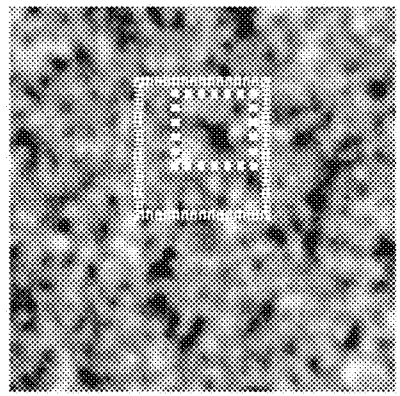


FIG.3B

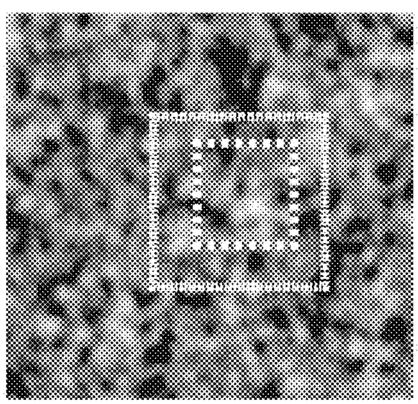


FIG.3C

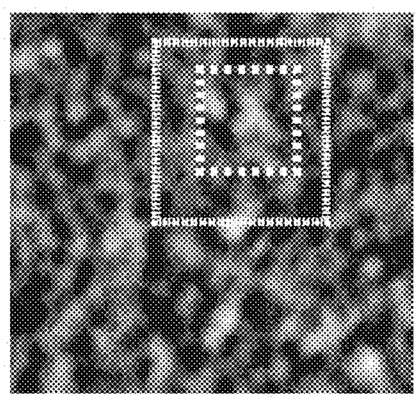


FIG.3D

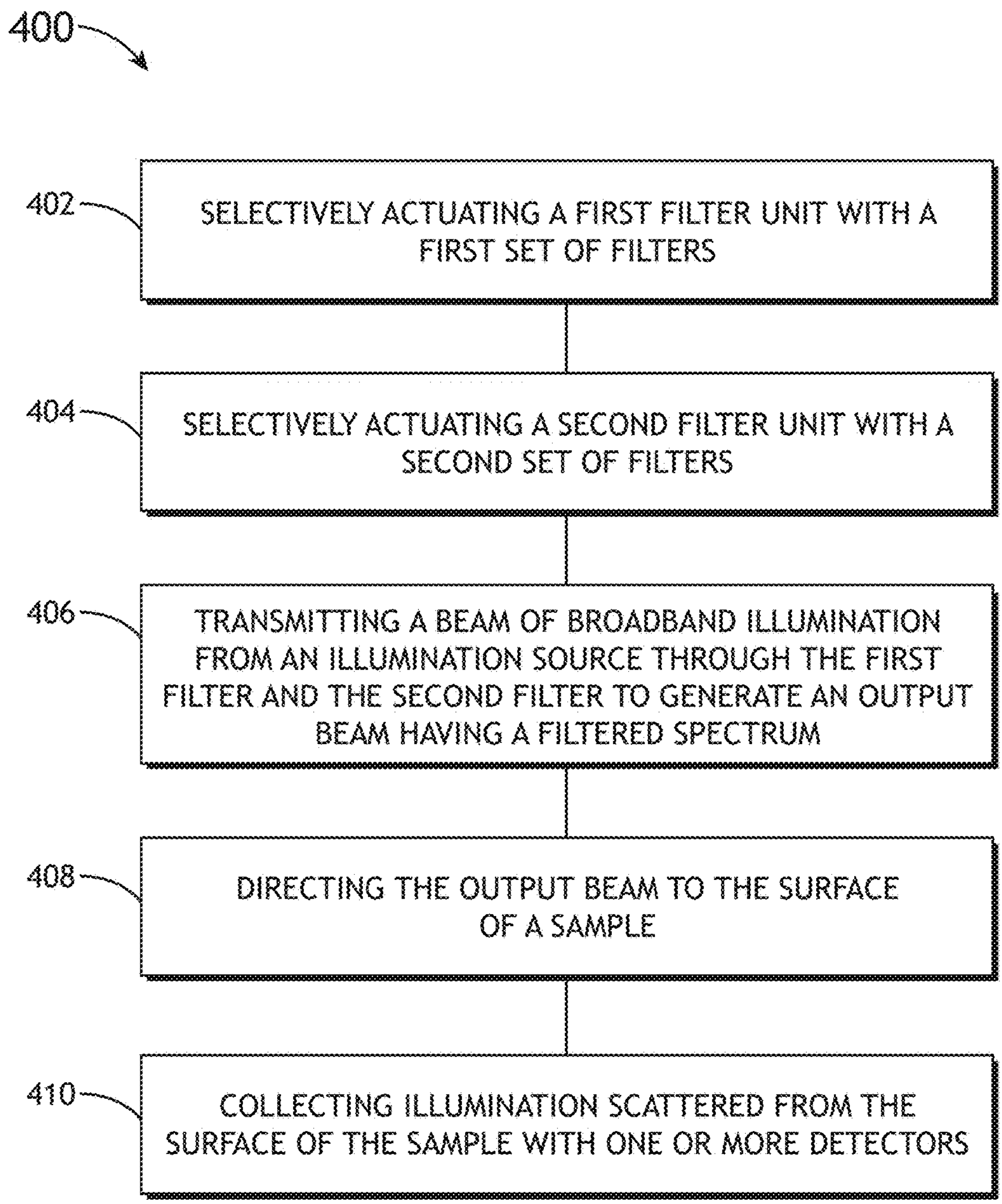

400
402
SELECTIVELY ACTUATING A FIRST FILTER UNIT WITH A FIRST SET OF FILTERS
404
SELECTIVELY ACTUATING A SECOND FILTER UNIT WITH A SECOND SET OF FILTERS
406
TRANSMITTING A BEAM OF BROADBAND ILLUMINATION FROM AN ILLUMINATION SOURCE THROUGH THE FIRST FILTER AND THE SECOND FILTER TO GENERATE AN OUTPUT BEAM HAVING A FILTERED SPECTRUM
408
DIRECTING THE OUTPUT BEAM TO THE SURFACE OF A SAMPLE
410
COLLECTING ILLUMINATION SCATTERED FROM THE SURFACE OF THE SAMPLE WITH ONE OR MORE DETECTORS

FIG. 4

FILTER ASSEMBLY FOR PROVIDING ADJUSTABLE SPECTRAL CAPABILITIES IN A BROADBAND INSPECTION SYSTEM

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present application claims the benefit under 35 U.S.C. § 119(e) of U.S. Provisional Application Ser. No. 62/485,505, filed Apr. 14, 2017, entitled FLEXIBLE SPECTRUM FOR BROAD BAND PLASMA WAFER INSPECTION SYSTEMS, naming Jeremy Nesbitt, Jagadeesh Kumar, and David C. Oram as inventors, which is incorporated herein by reference in the entirety.

TECHNICAL FIELD

[0002] The disclosure generally relates to the field of sample inspection and defect detection, and, more particularly, to an inspection system equipped with a filter assembly for providing adjustable spectral capabilities in a broadband inspection system.

BACKGROUND

[0003] As the demand for integrated circuits having ever-smaller device features continues to increase, the need for improved inspection systems for inspection of these ever-shrinking devices continues to grow. Some inspection systems incorporate broadband light sources, such as, but not limited to, a laser-sustained plasma (LSP) broadband light source.

[0004] While inspecting a sample, such as a semiconductor wafer, various types of defects produce different signal responses based on the wavelength used during inspection. As a result, in many cases, a particular type of defect may be inspected most efficiently using a specific spectral band. Current wafer inspection systems utilize a single wheel containing various band pass spectral filters. The wheel may be rotated such that a single band pass filter may be placed in the beam of illumination, thereby filtering the light used for inspection to the spectral range associated with that filter. One drawback of current systems is that, due to space constraints, the wheels are only able to hold approximately ten separate filters at any one time. Another drawback of current systems is that a separate filter design is needed for each separate spectral range desired. The need for many spectral ranges, and therefore the need for many filters, increases cost and the time required to switch between various spectral ranges. Additionally, simply increasing the size of the wheel to accommodate additional filters may not be possible due to space constraints. Therefore, there exists a need for a system and method which cure one or more of the shortcomings of the previous approaches identified above.

SUMMARY

[0005] A filter apparatus for providing adjustable spectral capabilities in a broadband inspection system is disclosed, in accordance with one or more illustrative embodiments of the present disclosure. In one embodiment, the filter apparatus includes a first filter unit. In another embodiment, the first filter unit includes a first set of filters. In another embodiment, the filter apparatus includes a second filter unit. In another embodiment, the second filter unit includes a second set of filters. In another embodiment, at least one of the first set of filters or the second set of filters includes a first filter and a second filter having one or more filtering characteristics different from the first filter. In another embodiment, the filter apparatus includes a first motor coupled to the first filter unit. In another embodiment, the first motor is configured to selectively actuate a selected filter of the first filter unit into a beam of broadband illumination from an illumination source. Similarly, in another embodiment, the filter apparatus includes a second motor coupled to the second filter unit. In another embodiment, the second motor is configured to selectively actuate a selected filter of the second filter unit into the beam of broadband illumination from an illumination source.

[0006] A system for providing adjustable spectral capabilities in a broadband inspection system is disclosed, in accordance with one or more illustrative embodiments of the present disclosure. In one embodiment, the system includes an illumination source configured to generate broadband illumination. In another embodiment, the system includes a filter assembly. In one embodiment, the filter assembly includes a first filter unit. In another embodiment, the first filter unit includes a first set of filters. In another embodiment, the filter assembly includes a second filter unit. In another embodiment, the second filter unit includes a second set of filters. In another embodiment, at least one of the first set of filters or the second set of filters includes a first filter and a second filter having one or more filtering characteristics different from the first filter.

[0007] In another embodiment, the filter assembly includes a first motor coupled to the first filter unit. In another embodiment, the first motor is configured to selectively actuate a selected filter of the first filter unit into a beam of broadband illumination. In another embodiment, the filter assembly includes a second motor coupled to the second filter unit. In another embodiment, the second motor is configured to selectively actuate a selected filter of the second filter unit into the beam of broadband illumination.

[0008] It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not necessarily restrictive of the invention as claimed. The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate embodiments of the invention, and, together with the general description, serve to explain the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The numerous advantages of the disclosure may be better understood by those skilled in the art by reference to the accompanying figures in which:

[0010] FIG. **1**A illustrates a block diagram of a system for providing adjustable spectral capabilities in a broadband inspection system in a bright field configuration, in accordance with one or more embodiments of the present disclosure.

[0011] FIG. **1**B illustrates a simplified schematic diagram of a system for providing adjustable spectral capabilities in a broadband inspection system in a dark field configuration, in accordance with one or more embodiments of the present disclosure.

[0012] FIG. **1**C illustrates a simplified conceptual diagram of a filter wheel assembly for providing adjustable spectral capabilities in a broadband inspection system, in accordance with one or more embodiments of the present disclosure.

[0013] FIG. **1**D illustrates a simplified schematic diagram of a wheel including a set of filters, in accordance with one or more embodiments of the present disclosure.

[0014] FIG. **1**E illustrates a simplified schematic diagram of a wheel including a set of filters, in accordance with one or more embodiments of the present disclosure.

[0015] FIG. **1**F illustrates a simplified conceptual diagram of a system for providing adjustable spectral capabilities in a broadband inspection system, in accordance with one or more embodiments of the present disclosure.

[0016] FIG. **1**G illustrates a simplified schematic diagram of a filter assembly for providing adjustable spectral capabilities in a broadband inspection system, in accordance with one or more embodiments of the present disclosure.

[0017] FIG. **1**H illustrates a simplified schematic diagram of a sliding filter device, in accordance with one or more embodiments of the present disclosure.

[0018] FIG. **1**I illustrates a simplified schematic diagram of a sliding filter device, in accordance with one or more embodiments of the present disclosure.

[0019] FIG. **2**A illustrates a graph of intensity as a function of wavelength of a broadband output as a function of wavelength after filtering with a first filter and a second filter, in accordance with one or more embodiments of the present disclosure.

[0020] FIG. **2**B illustrates a graph of intensity as a function of wavelength of a resulting narrow spectral band, in accordance with one or more embodiments of the present disclosure.

[0021] FIG. **2**C illustrates a graph of intensity as a function of wavelength of a broadband output as a function of wavelength after filtering with a first filter and a second filter, in accordance with one or more embodiments of the present disclosure.

[0022] FIG. **2**D illustrates a graph of intensity as a function of wavelength of a resulting broad spectral band, in accordance with one or more embodiments of the present disclosure.

[0023] FIG. **3**A illustrates an image of a defect acquired using illumination of a wavelength range 260-285 nm, in accordance with one or more embodiments of the present disclosure.

[0024] FIG. **3**B illustrates an image of a defect acquired using illumination of a wavelength range 260-303 nm, in accordance with one or more embodiments of the present disclosure.

[0025] FIG. **3**C illustrates an image of a defect acquired using illumination of a wavelength range 260-320 nm, in accordance with one or more embodiments of the present disclosure.

[0026] FIG. **3**D illustrates an image of a defect acquired using illumination of a wavelength range 421-450 nm, in accordance with one or more embodiments of the present disclosure.

[0027] FIG. **4** illustrates a flowchart of a method for providing adjustable spectral capabilities in a broadband inspection system, in accordance with one or more embodiments of the present disclosure.

DETAILED DESCRIPTION

[0028] It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not necessarily restrictive of the invention as claimed. The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate embodiments of the invention and, together with the general description, serve to explain the principles of the invention.

[0029] Reference will now be made in detail to the subject matter disclosed, which is illustrated in the accompanying drawings.

[0030] Referring generally to FIGS. **1**A through **3**D, an apparatus and system for providing adjustable spectral capabilities in a broadband inspection system are described, in accordance with one or more embodiments of the present disclosure.

[0031] Embodiments of the present disclosure are directed to a filter assembly for providing adjustable spectral capabilities in a broadband inspection system. Embodiments of the present disclosure are directed to a filter assembly including two or more filter units, wherein each filter unit includes multiple filters. The utilization of the filter assembly of the present disclosure causes broadband illumination emitted from an illumination source to be filtered at least twice: first by a first filter on a first filter unit, then by a second filter on a second filter unit. The resulting filtered spectrum, which may be used for sample inspection, would therefore be a product of the two or more filters. Such a configuration allows broadband light to be more flexibly filtered to a desired spectral range. It is noted herein that the increased number of filter configuration combinations allows a user increased flexibility to modify the characteristics of a beam of broadband illumination to be used for inspection. It is further noted herein that the implementation of a filter assembly including two or more separate filter units serves to decrease cost, increase the number of available spectral bands, and alleviate space constraints.

[0032] While much of the present disclosure focuses on the implementation of the embodiments of the present disclosure in the context of semiconductor wafer inspection, this is not a limitation on the present disclosure and is provided merely for illustrative purposes. It is noted herein that the embodiments of the present disclosure may be extended to any inspection or imaging setting known in the optical arts, including, but not limited to, semiconductor device inspection, reticle inspection, biological specimen inspection, and the like.

[0033] FIG. **1**A illustrates a block diagram of a system for providing adjustable spectral capabilities in a broadband inspection system in a bright field configuration, in accordance with one or more embodiments of the present disclosure.

[0034] In one embodiment, the system **100** includes a filter assembly **102**, an illumination source **104**, a sample stage **108**, a detector **110**, and/or a controller **112**.

[0035] In one embodiment, the illumination source **104** is configured to emit broadband illumination **122** which may be used to illuminate a portion of a sample **106** secured by the sample stage **108**. The illumination source **104** may include any illumination source known in the art of sample inspection. For example, the illumination source **104** may include, but is not limited to, a laser produced plasma (LPP) broadband source, a discharge broadband source, or a broadband laser. Further, the illumination source **104** may illuminate a portion of the sample **106** with illumination of any spectral range known in the art of sample inspection. For example, the illumination source **104** may emit illumination in the infrared (IR), visible, ultra-violet (UV), or deep ultra-violet (DUV) spectral ranges.

[0036] The sample **106** may include, but is not limited to, a wafer, such as a semiconductor wafer (e.g., silicon wafer). The sample stage **108** may be configured to move or rotate the sample, using any actuation method known in the art, in order to facilitate inspection of the sample **106**.

[0037] It is noted that the system **100** of the present disclosure may be configured as any inspection system known in the art. For example, as shown in FIG. **1**A, the system **100** may be configured as a bright field (BF) inspection system. Alternatively, as shown in FIG. **1**B, the system **100** may be configured as a dark field (DF) inspection system. Applicant notes that the optical configurations depicted in FIGS. **1**A and **1**B are provided merely for illustrative purposes and should not be interpreted as limiting. In a general sense, the system **100** of the present disclosure may include any set of imaging and optical elements suitable for imaging the surface of a sample **106**. Examples of wafer inspection tools are described in detail in U.S. Pat. No. 7,092,082, U.S. Pat. No. 6,702,302, U.S. Pat. No. 6,621,570, and U.S. Pat. No. 5,805,278, which are each herein incorporated by reference.

[0038] Referring again to FIG. **1**A, in one embodiment, the filter assembly **102** is configured to receive broadband illumination **122** emitted from the illumination source **104** and filter the broadband illumination **122** into a filtered spectrum **124**. In another embodiment, the illumination having the filtered spectrum **124** may be directed to the surface of a sample **106**.

[0039] In another embodiment, the system **100** may include one or more illumination optics **126**, **128** for directing and/or focusing the illumination emitted by illumination source **104** onto a portion of the sample **106**. The illumination optics **126**, **128** may include any optical elements known in the art. For example, the illumination optics **126**, **128** may include, but are not limited to, one or more diffractive optical elements, one or more lenses, one or more mirrors, one or more filters, and the like. In another embodiment, the system **100** includes one or more beam splitters **120** for directing the illumination emitted by illumination source **104** onto a portion of the sample **106**.

[0040] In one embodiment, the one or more detectors **110** are configured to collect illumination from the surface of sample **106** (e.g. illumination scattered from one or more defects, illumination reflected from the surface of sample **106**, and the like). The detectors **110** may include any detector(s) known in the art of sample inspection. For example, detectors **110** may include, but are not limited to, CCD detectors or TDI-CCD detectors.

[0041] In another embodiment, the controller **112** includes one or more processors **114**. In another embodiment, the one or more processors **114** are configured to execute a set of program instructions stored in memory **116**. In another embodiment, the set of program instructions are configured to cause one or more components of the filter assembly **102** to actuate in order to selectively alter one or more characteristics of the filtered spectrum **124**. In another embodiment, the system **100** includes a user interface **118** communicatively coupled with the controller **112**.

[0042] The one or more processors **114** of controller **112** may include any one or more processing elements known in the art. In this sense, the one or more processors **114** may include any microprocessor-type device configured to execute software algorithms and/or instructions. In one embodiment, the one or more processors **114** may consist of a desktop computer, mainframe computer system, workstation, image computer, parallel processor, or other computer system (e.g., networked computer) configured to execute a program configured to operate the system **100**, as described throughout the present disclosure. It should be recognized that the steps described throughout the present disclosure may be carried out by a single computer system or, alternatively, multiple computer systems. In general, the term "processor" may be broadly defined to encompass any device having one or more processing elements, which execute program instructions from memory **116**. Moreover, different subsystems of the system **100** (e.g., filter assembly **102**, or user interface **118**) may include processor or logic elements suitable for carrying out at least a portion of the steps described throughout the present disclosure. Therefore, the above description should not be interpreted as a limitation on the present disclosure but merely an illustration.

[0043] The memory **116** may include any storage medium known in the art suitable for storing program instructions executable by the associated one or more processors **114**. For example, the memory **116** may include a non-transitory memory medium. For instance, the memory **116** may include, but is not limited to, a read-only memory, a random access memory, a magnetic or optical memory device (e.g., disk), a magnetic tape, a solid state drive, and the like. In another embodiment, the memory **116** is configured to store one or more results from the filter assembly **102**, the detectors **110**, and/or the output of the various steps described herein. It is further noted that memory **116** may be housed in a common controller housing with the one or more processors **114**. In an alternative embodiment, the memory **116** may be located remotely with respect to the physical location of the processors and controller **112** For instance, the one or more processors **114** of controller **112** may access a remote memory (e.g., server), accessible through a network (e.g., internet, intranet, and the like). In another embodiment, the memory **116** maintains program instructions for causing the one or more processors **114** to carry out the various steps described through the present disclosure.

[0044] In one embodiment, the user interface **118** is communicatively coupled to the controller **112**. The user interface **118** may include any user input device known in the art. For example, the user input device may include, but is not limited to, a keyboard, a keypad, a touchscreen, a scroll bar, a steering wheel, a joystick, or the like. Those skilled in the art should recognize that a large number of user input devices may be suitable for implementation in the present invention, and that the present invention is not limited to those user input devices listed herein.

[0045] In other embodiments, the user interface **118** includes a display used to display data of the system **100** or the filter assembly **102** to the user. The display of the user interface **118** may include any display known in the art. For example, the display may include, but is not limited to, a liquid crystal display (LCD), an organic light-emitting diode (OLED) based display or a CRT display. Those skilled in the art should recognize that any display device capable of integration with a user interface **118** is suitable for implementation in the present disclosure. In another embodiment, a user may input selections and/or instructions responsive to data displayed to the user via the user interface **118**.

[0046] FIG. **1**C illustrates a simplified conceptual diagram of a filter assembly **102**, in accordance with one or more embodiments of the present disclosure.

[0047] In this embodiment, the filter assembly **102** is a filter wheel assembly. In one embodiment, the filter assembly **102** includes two or more filter wheels **126**, **127**. In one embodiment, the first filter wheel **126** includes a first set of filters **132**. In another embodiment, the second filter wheel **127** includes a second set of filters **133**. In another embodiment, when in operation, the filter wheel assembly may be controlled such that the first set of filters **126** includes an "active" filter **130**, which is aligned within the beam of illumination **121** emitted from illumination source **104**. Similarly, the second set of filters **127** may include an active filter **131**, which is also aligned within the beam of illumination **121** emitted from illumination source **104**.

[0048] In another embodiment, the filter assembly **102** includes two or more motors **128**, **129** which are rotationally coupled to the two or more filter wheels **126**, **127**. In another embodiment, the motors **128**, **129** are configured such that each filter wheel **126**, **127** may be rotated independently with respect to the other filter wheel **126**, **127**. For example, a first motor **128** may be configured such that it may rotate the first filter wheel **126** independently with respect to the second filter wheel **127**. By way of another example, a second motor **129** may be configured such that it may rotate the second filter wheel **127** independently with respect to the first filter wheel **126**.

[0049] In one embodiment, the first filter wheel **126** may include a first set of filters **132**. In another embodiment, the second filter wheel **127** may include a second set of filters **133**. In another embodiment, the first set of filters **132** includes a first filter and a second filter such that the first and second filters have one or more different filtering characteristics. In another embodiment, the second set of filters **133** includes a first filter and a second filter such that the first and second filters have one or more different filtering characteristics.

[0050] In another embodiment, motors **128**, **129** may be configured to selectively rotate the filter wheels **126**, **127** such that a selected filter of each set of filters **132**, **133** is rotated into the beam of illumination. For example, the first motor **128** may be controlled to selectively rotate the first filter wheel **126** independently of the second filter wheel **127** such that a selected filter of the first set of filters **132** is rotated into the beam of illumination **121** from illumination source **104**. By way of another example, the second motor **129** may be controlled to selectively rotate the second filter wheel **127** independently of the first filter wheel **126** such that a selected filter of the second set of filters **133** is rotated into the beam of illumination **121** from illumination source **104**.

[0051] It is noted that the independent rotation of filter wheels **126**, **127** allows for many filter combinations among sets of filters **132**, **133**. For example, a first wheel configured to rotate independently with respect to a second wheel may include n unique individual filters. The second wheel, which is configured to rotate independently with respect to the first wheel, may include m unique individual filters. In this example, the total number of unique filter combinations N may be found by the equation $N=m*n$.

[0052] FIGS. **1**D and **1**E illustrate simplified schematic diagrams of filter wheels **126**, **127** including sets of filters **132** and **133**, in accordance with one or more embodiments of the present disclosure. As previously discussed, the first filter wheel **126** and the second filter wheel **127** may be configured to rotate independently with respect to each other. In this example, the first filter wheel **126** has 12 individual filters (i.e., n=12) and the second filter wheel **127** has 12 individual filters (i.e., m=12). In this example, filter wheels **126** and **127** are able to produce **144** unique filter combinations (i.e., $N=12*12=144$). It is contemplated that additional wheels including additional sets of filters may be utilized to further modify one or more characteristics of broadband illumination **122**, which may produce additional unique filter combinations.

[0053] In another embodiment, sets of filters **132**, **133** may include filters configured to transmit an output spectral range between approximately 10 nm to 600 nm. In another embodiment, sets of filters **132**, **133** may each include 5-25 individual filters. For instance, sets of filters **132**, **133** may include 12 individual filters, as depicted in FIGS. **1**D and **1**E. It is noted that, while filter wheels **126**, **127** depicted in FIGS. **1**D and **1**E each have 12 individual filters, this configuration is not a limitation on the scope of the present disclosure and is provided merely for illustrative purposes. It is contemplated herein that each filter wheel (or other filter holding mechanism) may include any number of filters.

[0054] In another embodiment, the first set of filters **132** includes a low pass filter and/or a high pass filter. In another embodiment, the second set of filters **133** includes at least one of a low pass filter or a high pass filter. In yet another embodiment, the first set of filters **132** includes one or more high pass filters, and the second set of filters **133** includes one or more low pass filters. In yet another embodiment, the first set of filters **132** includes one or more low pass filters, and the second set of filters **133** includes one or more high pass filters. In another embodiment, a set of prisms could be used in place of sets of filters in order to achieve spectral separation based on wavelength.

[0055] In another embodiment, filter wheels **126**, **127** may be rotated such that one or fewer individual filters are placed in the beam of illumination **121**. For example, referring to FIG. **1**D, first motor **128** may selectively rotate first filter wheel **126** such that a selected filter is rotated into the beam of illumination **121**. In this example, filter **132**A was selectively rotated into the beam of illumination **121**. Thus, in this example, filter **132**A is the "active" filter **130** and filters **132**B-n, which are not in the beam of illumination **121**, are "inactive." In another example, referring to FIG. **1**E, second motor **129** may selectively rotate second filter wheel **127** such that a selected filter is rotated into the beam of illumination **121**. In this example, filter **133**A is placed in the beam of illumination **121**. Thus, in this example, filter **133**A is the "active" filter **131** and filters **133**B-m, which are not in the beam of illumination **121**, are "inactive."

[0056] Referring again to FIG. **1**C, in another embodiment, controller **112** is configured to cause one or more filter wheels **126**, **127** of the filter assembly **102** to selectively rotate a selected filter of the sets of filters **132**, **133** into the beam of illumination **121** in order to control one or more characteristics of the broadband illumination **122**. For example, the characteristics and location of each individual filter of the sets of filters **132**, **133** may be stored in memory **116**. Using the known locations of each of the individual filters on the filter wheels **126**, **127**, the one or more processors **114** of controller **112** may execute a set of program instructions configured to cause the motors **128**,

129 to selectively rotate filter wheels **126**, **127** such that a first filter in the first set of filters **132** and/or a second filter in the second set of filters is rotated into the beam of illumination **121**.

[0057] FIG. **1**F illustrates a simplified schematic diagram of system **100** for providing adjustable spectral capabilities in a broadband inspection system, in accordance with one or more embodiments of the present disclosure.

[0058] In one embodiment, as shown in FIG. **1**F, system **100** may include a filter wheel assembly, as pictured in FIG. **1**C.

[0059] As stated herein, a single defect, or type of defect, may be examined most effectively using a particular spectral band. This tendency may be seen with reference to FIGS. **3**A-**3**D. FIGS. **3**A-**3**D depict images of a defect inspected using varying spectral ranges, in accordance with one embodiment of the present disclosure. FIG. **3**A depicts an image of a defect inspected using illumination with a wavelength range of 260-285 nanometers. FIGS. **3**B-**3**D depict images of the same defect inspected using illumination with ranges of 260-303, 260-320, and 421-450 nanometers, respectively. As can be seen in FIGS. **3**A-**3**D, a single defect may produce varying responses to varying spectral bands.

[0060] Based on the tendency of defects to produce varying responses to varying spectral bands, system **100** may be used to calibrate and/or optimize an inspection system, in accordance with one or more embodiments of the present disclosure. For example, the controller **112** may direct the first motor **128** to rotate the first filter wheel **126** to selectively rotate a first selected filter of the first set of filters **132** into the beam of illumination **121**. Similarly, the controller **112** may also direct the second motor **129** to rotate the second filter wheel **127** to selectively rotate a first selected filter of the second set of filters **133** into the beam of illumination **121**. The combined configuration of filter wheels **126**, **127** may be stored in memory **116** as a first configuration. A user may provide system **100** with a sample **106** which includes a known type of defect. System **100** may then be used inspect the surface of the sample **106** for the known defect with filter assembly **102** in the first configuration. Detectors **110** may then collect illumination scattered from the sample **106**. The level of illumination collected by the detectors **110** may be associated with the first configuration. By way of example, the collected illumination associated with the first configuration may be represented by the image depicted in FIG. **3**A.

[0061] Continuing with the same example, the controller **112** may cause one or more filter wheels **126**, **127** to selectively rotate one or more selected filters from sets of filters **132**, **133** into the beam of illumination **121**. This combined orientation of filter wheels **126**, **127** may be stored in memory **116** as a second configuration. Using the same sample **106** with a known type of defect as was used for the first configuration, system **100** may then be used to inspect the surface of the sample **106** using the second configuration. Detectors **110** may collect illumination scattered from the sample **106**, and the level of illumination collected may be associated with the second configuration. By further way of example, the collected illumination associated with the first configuration may be represented by the image depicted in FIG. **3**B.

[0062] Continuing with the same example, the process described previously may be used recursively to inspect the surface of sample **106** with every possible configuration of the filter assembly **102**. The illumination collected by detectors **110** may be associated with each possible configuration. Comparing the levels of illumination collected, a user and/or one or more computers or processors (not pictured) may determine the configuration which optimizes inspection for that particular type of defect. The optimal configuration may be the configuration which maximizes the illumination collected by detectors **110**. The optimal configuration for that particular type of defect may then be stored in memory **116** for future use. Furthermore, this process may be used for a wide array of possible defects. Repeating this process for a wide array of defect types would allow a user to create a list of possible defects and their corresponding optimal filter assembly **102** configurations. The list of optimal configurations for each type of defect may be stored in memory **116** for future use.

[0063] FIG. **1**G illustrates another embodiment of the present disclosure. FIG. **1**G illustrates a simplified schematic diagram of a filter assembly **102** for providing adjustable spectral capabilities in a broadband inspection system, in accordance with one or more embodiments of the present disclosure. FIG. **1**G depicts one possible alternative embodiment to the filter assembly **102** of system **100**.

[0064] In one embodiment, filter assembly **102** is a filter slide assembly, as depicted in FIG. **1**G. In one embodiment, the filter assembly **102** includes two or more sliding units **134**, **135**. In another embodiment, sliding units **134**, **135** include sets of filters **138**, **139**. In another embodiment, a first set of filters **138** may include a first filter and a second filter having one or more filtering characteristics different from the first filter. Similarly, in another embodiment, a second set of filters **139** may include a first filter and a second filter having one or more filtering characteristics different from the first filter.

[0065] In another embodiment, the sets of filters **132**, **133** may include filters ranging from 10 nm to 600 nm. In one embodiment, sets of filters **138**, **139** may each include 5-25 individual filters. For example, sets of filters **138**, **139** on sliding units may each include 6 individual filters, as shown in FIGS. **1**H and **1**I. By way of another example, sets of filters **138**, **139** on sliding units **134**, **135** may each include 8-12 individual filters.

[0066] In another embodiment, sets of filters **138**, **139** may be configured such that one or fewer individual filters are aligned with the beam of illumination **121**. For example, in one embodiment, as depicted in FIG. **1**G, only one filter of the first set of filters **138** may be the "active" filter **136** aligned with the beam of illumination **121**. Similarly, in another embodiment, the second set of filters **139** may be configured such that only one filter of the second set of filters **139** may be the "active" filter **137** aligned with the beam of illumination **121**. In another embodiment, broadband illumination **122** passes through two or more "active" filters **136**, **137** located on the sliding units **134**, **135** and exits the filter assembly as illumination having a filtered spectrum **124**. It is contemplated that additional sliding units including additional sets of filters may be utilized to further modify one or more characteristics of broadband illumination **122**.

[0067] In another embodiment, filter assembly includes two or more motors **140**, **141**. In another embodiment, motors **140**, **141** are coupled to sliding units **134**, **135**. In another embodiment, motors **140**, **141** are configured to actuate sliding units **134**, **135**. In another embodiment, motors **140**, **141** are configured to selectively actuate selected filters of the sliding units **134**, **135** into the beam of illumination **121**. In another embodiment, motors **140**, **141** are configured to selectively actuate sliding units **134**, **135** independently with respect to each other. For example, a first motor **140** may be configured to selectively actuate a selected filter of a first sliding unit **134** into the beam of illumination **121** independently with respect to a second sliding unit **135**. In another example, the second motor **141** may be configured to selectively actuate a selected filter of the second sliding unit **135** into the beam of illumination **121** independently with respect to first sliding unit **134**.

[0068] It is noted that other possible configurations for filter assembly **102** have been contemplated. For example, in addition to the aforementioned configurations, filter assembly **102** may include, but is not limited to, a filter assembly **102** including sets of filter flaps, a filter assembly **102** including two or more sets of filters on rotating shafts, or the like.

[0069] FIGS. **1**H and **1**I illustrate simplified schematic diagrams of sliding units **134**, **135**. The sliding units **134**, **135** may be configured such that one or fewer individual filters is aligned with the beam of illumination. For example, as depicted in FIG. **1**H, only one individual filter is aligned with the beam of illumination **121** and is therefore the only "active" filter **136**. By way of another example, as depicted in FIG. **1**I, only one individual filter is aligned with the beam of illumination **121** and is therefore the only "active" filter **136**.

[0070] In another embodiment of the present invention, the filter assembly **102** includes a controller **112** communicatively coupled with motors **140**, **141**. In another embodiment, the controller **112** includes one or more processors **114**. In another embodiment, the one or more processors **114** are configured to execute a set of program instructions stored in memory **116**. In another embodiment, the set of program instructions are configured to cause one or more motors **140**, **141** of the filter sliding assembly to selectively actuate a selected filter of one or more sliding units **134**, **135** into the beam of illumination **121**.

[0071] The one or more processors **114** of controller **112** may include any one or more processing elements known in the art. In this sense, the one or more processors **114** may include any microprocessor-type device configured to execute software algorithms and/or instructions. In one embodiment, the one or more processors **114** may consist of a desktop computer, mainframe computer system, workstation, image computer, parallel processor, or other computer system (e.g., networked computer) configured to execute a program configured to operate the system **100**, as described throughout the present disclosure. It should be recognized that the steps described throughout the present disclosure may be carried out by a single computer system or, alternatively, multiple computer systems. In general, the term "processor" may be broadly defined to encompass any device having one or more processing elements, which execute program instructions from memory **116**. Moreover, different subsystems of the system **100** (e.g., filter assembly **102**, or user interface **118**) may include processor or logic elements suitable for carrying out at least a portion of the steps described throughout the present disclosure. Therefore, the above description should not be interpreted as a limitation on the present disclosure but merely an illustration.

[0072] The memory **116** may include any storage medium known in the art suitable for storing program instructions executable by the associated one or more processors **114**. For example, the memory **116** may include a non-transitory memory medium. For instance, the memory **116** may include, but is not limited to, a read-only memory, a random access memory, a magnetic or optical memory device (e.g., disk), a magnetic tape, a solid state drive, and the like. In another embodiment, the memory **116** is configured to store one or more results from the filter assembly **102**, the detectors **110**, and/or the output of the various steps described herein. It is further noted that memory **116** may be housed in a common controller housing with the one or more processors **114**. In an alternative embodiment, the memory **116** may be located remotely with respect to the physical location of the processors and controller **112**. For instance, the one or more processors **114** of controller **112** may access a remote memory (e.g., server), accessible through a network (e.g., internet, intranet, and the like). In another embodiment, the memory **116** maintains program instructions for causing the one or more processors **114** to carry out the various steps described through the present disclosure.

[0073] In another embodiment, the system **100** includes a user interface **118**. In one embodiment, the user interface **118** is communicatively coupled to the controller **112**. The user interface **118** may include any user input device known in the art. For example, the user interface **118** may include, but is not limited to, a keyboard, a keypad, a touchscreen, a scroll bar, a steering wheel, a joystick, or the like. Those skilled in the art should recognize that a large number of user input devices may be suitable for implementation in the present invention, and that the present invention is not limited to those user input devices listed within the present disclosure.

[0074] In other embodiments, the user interface **118** includes a display used to display data of the system **100** or the filter assembly **102** to the user. The display of the user interface **118** may include any display known in the art. For example, the display may include, but is not limited to, a liquid crystal display (LCD), an organic light-emitting diode (OLED) based display or a CRT display. Those skilled in the art should recognize that any display device capable of integration with a user interface **118** is suitable for implementation in the present disclosure. In another embodiment, a user may user may input selections and/or instructions responsive to data displayed to the user via the user interface **118**.

[0075] FIGS. **2**A-**2**D illustrate graphs of intensity vs. wavelength using varying filters in the present invention, in accordance with one embodiment of the present invention.

[0076] FIG. **2**A illustrates a graph **200** graphing intensity as a function of wavelength after filtering with two separate filters. In one embodiment, Filter **1** may be included in a set of filters located on a first filter unit of a filter assembly **102**. In another embodiment, Filter **2** may be included in a second set of filters located on a second filter unit of a filter assembly **102**. In one embodiment, as shown in FIG. **2**A, Filter **1** is a high-pass filter, only passing illumination above a particular wavelength. In another embodiment, as shown in FIG. **2**A, Filter **2** is a low-pass filter, only passing illumination below a particular wavelength.

[0077] FIG. **2**B illustrates a graph **210** depicting the resulting narrow spectral band obtained by system **100** using Filter **1** and Filter **2** from graph **200**, in accordance with one embodiment of the present disclosure. As can be seen in graph **210**, the resulting spectrum is a product of the high-pass filter (Filter **1**) and the low-pass filter (Filter **2**) from graph **200**.

[0078] FIG. **2**C illustrates a graph **220** graphing intensity as a function of wavelength after filtering with two separate filters. As shown in FIG. **2**C, Filter **1** is a high-pass filter, only passing illumination above a particular wavelength. In another embodiment, as shown in FIG. **2**C, Filter **2** is a low-pass filter, only passing illumination below a particular wavelength.

[0079] FIG. **2**D illustrates a graph **230** depicting the resulting broad spectral band obtained by system **100** using Filter **1** and Filter **2** from graph **220**, in accordance with one embodiment of the present disclosure. As can be seen in graph **230**, the resulting spectral band is a product of the high-pass filter (Filter **1**) and the low-pass filter (Filter **2**) from graph **220**.

[0080] Comparing the resulting spectrums from graphs **230** and **210**, it can be seen the set of filters used by system **100** in graph **200** result in a narrower filtered spectral band, whereas the set of filters used by system **100** in graph **200** result in a wider filtered spectral band. It can be appreciated from these graphs, as well as the foregoing disclosure, that the filter assembly **102** is highly customizable, and can be utilized to filter an inspection system to a wide array of spectral ranges.

[0081] FIG. **4** illustrates a flowchart of a method **400** for providing adjustable spectral capabilities in a broadband inspection system, in accordance with one or more embodiments of the present disclosure. It is noted herein that the steps of method **400** may be implemented all or in part by system **100**. It is further noted, however, that method **400** is not limited to the system **100** in that additional or alternative system-level embodiments may carry out all or part of the steps of method **400**.

[0082] In step **402**, first filter with a first set of filters is selectively actuated. Similarly, in step **404**, a second filter with a second set of filters is selectively actuated. In one embodiment, as described herein, a controller **112** may direct a first motor to selectively actuate a first filter unit in order to actuate a particular filter on the first filter unit. Similarly, in another embodiment, the controller **112** may direct a second motor to selectively actuate a second filter unit in order to actuate a particular filter on the second filter unit into the beam of illumination.

[0083] In step **406**, a beam of broadband illumination from an illumination source is transmitted through the first filter and the second filter to generate an output beam having a filtered spectrum. In step **408**, the output beam is directed to the surface of sample. In step **408**, illumination scattered from the surface of the sample is collected with one or more detectors.

[0084] All of the methods described herein may include storing results of one or more steps of the method embodiments in a storage medium. The storage medium may include any storage medium described herein or any other suitable storage medium known in the art. After the results have been stored, the results can be accessed in the storage medium and used by any of the method or system embodiments described herein, formatted for display to a user, used by another software module, method, or system, etc.

[0085] It is further contemplated that each of the embodiments of the method described above may include any other step(s) of any other method(s) described herein. In addition, each of the embodiments of the method described above may be performed by any of the systems described herein.

[0086] The herein described subject matter sometimes illustrates different components contained within, or connected with, other components. It is to be understood that such depicted architectures are merely exemplary, and that in fact many other architectures can be implemented which achieve the same functionality. In a conceptual sense, any arrangement of components to achieve the same functionality is effectively "associated" such that the desired functionality is achieved. Hence, any two components herein combined to achieve a particular functionality can be seen as "associated with" each other such that the desired functionality is achieved, irrespective of architectures or intermedial components. Likewise, any two components so associated can also be viewed as being "connected," or "coupled," to each other to achieve the desired functionality, and any two components capable of being so associated can also be viewed as being "couplable," to each other to achieve the desired functionality. Specific examples of couplable include but are not limited to physically mateable and/or physically interacting components and/or wirelessly interactable and/or wirelessly interacting components and/or logically interacting and/or logically interactable components.

[0087] Furthermore, it is to be understood that the invention is defined by the appended claims. It will be understood by those within the art that, in general, terms used herein, and especially in the appended claims (e.g., bodies of the appended claims) are generally intended as "open" terms (e.g., the term "including" should be interpreted as "including but not limited to," the term "having" should be interpreted as "having at least," the term "includes" should be interpreted as "includes but is not limited to," etc.). It will be further understood by those within the art that if a specific number of an introduced claim recitation is intended, such an intent will be explicitly recited in the claim, and in the absence of such recitation no such intent is present. For example, as an aid to understanding, the following appended claims may contain usage of the introductory phrases "at least one" and "one or more" to introduce claim recitations. However, the use of such phrases should not be construed to imply that the introduction of a claim recitation by the indefinite articles "a" or "an" limits any particular claim containing such introduced claim recitation to inventions containing only one such recitation, even when the same claim includes the introductory phrases "one or more" or "at least one" and indefinite articles such as "a" or "an" (e.g., "a" and/or "an" should typically be interpreted to mean "at least one" or "one or more"); the same holds true for the use of definite articles used to introduce claim recitations. In addition, even if a specific number of an introduced claim recitation is explicitly recited, those skilled in the art will recognize that such recitation should typically be interpreted to mean at least the recited number (e.g., the bare recitation of "two recitations," without other modifiers, typically means at least two recitations, or two or more recitations). Furthermore, in those instances where a convention analogous to "at least one of A, B, and C, etc." is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., "a system having at least one of A, B, and C" would include but not be limited to systems that have A alone, B alone, C alone, A and

B together, A and C together, B and C together, and/or A, B, and C together, etc.). In those instances where a convention analogous to "at least one of A, B, or C, etc." is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., "a system having at least one of A, B, or C" would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). It will be further understood by those within the art that virtually any disjunctive word and/or phrase presenting two or more alternative terms, whether in the description, claims, or drawings, should be understood to contemplate the possibilities of including one of the terms, either of the terms, or both terms. For example, the phrase "A or B" will be understood to include the possibilities of "A" or "B" or "A and B."

[0088] It is believed that the present disclosure and many of its attendant advantages will be understood by the foregoing description, and it will be apparent that various changes may be made in the form, construction and arrangement of the components without departing from the disclosed subject matter or without sacrificing all of its material advantages. The form described is merely explanatory, and it is the intention of the following claims to encompass and include such changes. Furthermore, it is to be understood that the invention is defined by the appended claims.

What is claimed is:

1. A filter apparatus for providing a filtered spectrum in a broadband inspection system comprising:

a first filter unit, the first filter unit including a first plurality of filters;

an additional filter unit, the additional filter unit including an additional plurality of filters, wherein at least one of the first plurality of filters or the additional plurality of filters includes a first filter and a second filter having one or more filtering characteristics different from the first filter;

a first motor coupled to the first filter unit, wherein the first motor is configured to selectively actuate a selected filter of the first filter unit into a beam of broadband illumination from an illumination source; and

an additional motor coupled to the additional filter unit, wherein the additional motor is configured to selectively actuate a selected filter of the additional filter unit into the beam of broadband illumination, wherein the selected filter of the first filter unit and the selected filter of the additional filter unit are configured to filter broadband illumination from an illumination source to provide a selected filtered spectrum for broadband inspection.

2. The filter apparatus of claim **1**, wherein the first plurality of filters includes 5 to 25 filters.

3. The filter apparatus of claim **1**, wherein the additional plurality of filters includes 5 to 25 filters.

4. The filter apparatus of claim **1**, wherein the first plurality of filters includes at least one of a low pass filter or a high pass filter.

5. The filter apparatus of claim **1**, wherein the additional plurality of filters includes at least one of a low pass filter or a high pass filter.

6. A filter wheel apparatus for providing a filtered spectrum in a broadband inspection system comprising:

a first filter wheel, the first filter wheel including a first plurality of filters,

an additional filter wheel, the additional filter wheel including an additional plurality of filters, wherein at least one of the first plurality of filters or the additional plurality of filters includes a first filter and a second filter having one or more filtering characteristics different from the first filter;

a first motor coupled to the first filter wheel, wherein the first motor is configured to selectively rotate a selected filter of the first filter wheel into a beam of broadband illumination from an illumination source; and

an additional motor coupled to the additional filter wheel, wherein the additional motor is configured to selectively rotate a selected filter of the additional filter wheel into the beam of broadband illumination, wherein the selected filter of the first filter wheel and the selected filter of the additional filter wheel are configured to filter broadband illumination from an illumination source to provide a selected filtered spectrum for broadband inspection.

7. The filter wheel apparatus of claim **6**, wherein the first plurality of filters includes 5 to 25 filters.

8. The filter wheel apparatus of claim **6**, wherein the additional plurality of filters includes 5 to 25 filters.

9. The filter wheel apparatus of claim **6**, wherein the first plurality of filters includes at least one of a low pass filter or a high pass filter.

10. The filter wheel apparatus of claim **6**, wherein the additional plurality of filters includes at least one of a low pass filter or a high pass filter.

11. A system comprising:

an illumination source, the illumination source configured to generate a beam of broadband illumination; and

a filter assembly comprising:

a first filter unit including a first plurality of filters;

an additional filter unit including an additional plurality of filters, wherein at least one of the first plurality of filters or the additional plurality of filters includes a first filter and a second filter having one or more filtering characteristics different from the first filter;

a first motor coupled to the first filter unit, wherein the first motor is configured to selectively actuate a selected filter of the first filter unit into the beam of broadband illumination; and

an additional motor coupled to the additional filter unit, wherein the additional motor is configured to selectively actuate a selected filter of the additional filter unit into the beam of broadband illumination, wherein the selected filter of the first filter unit and the selected filter of the additional filter unit are configured to filter the broadband illumination from the illumination source to provide a selected filtered spectrum for broadband inspection.

12. The system of claim **11**, further comprising:

a controller communicatively coupled to the first motor and the additional motor, wherein the controller includes one or more processors configured to execute a set of program instructions, wherein the program instructions are configured to cause the one or more processors to control a positional state of at least one of the first filter unit or the additional filter unit via at least one of the first motor or additional motor to achieve one or more selected spectral characteristics in the beam of broadband illumination.

13. The system of claim **11**, wherein the first plurality of filters includes 5 to 25 filters.

14. The system of claim **11**, wherein the additional plurality of filters includes 5 to 25 filters.

15. The system of claim **11**, wherein the first plurality of filters includes at least one of a low pass filter or a high pass filter.

16. The system of claim **11**, wherein the additional plurality of filters includes at least one of a low pass filter or a high pass filter.

17. The system of claim **11**, wherein the illumination source configured to emit broadband illumination comprises at least one of a laser sustained plasma (LSP), a discharge broadband source, or a broadband laser.

18. A system comprising:

an illumination source, the illumination source configured to generate a beam of broadband illumination; and

a filter assembly comprising:

a first filter wheel including a first plurality of filters;

an additional filter wheel including an additional plurality of filters, wherein at least one of the first plurality of filters or the additional plurality of filters includes a first filter and a second filter having one or more filtering characteristics different from the first filter;

a first motor rotationally coupled to the first filter wheel, wherein the first motor is configured to selectively rotate a selected filter of the first filter wheel into the beam of broadband illumination; and

an additional motor rotationally coupled to the additional filter wheel, wherein the additional motor is configured to selectively rotate a selected filter of the additional filter wheel into the beam of broadband illumination, wherein the selected filter of the first filter wheel and the selected filter of the additional filter wheel are configured to filter broadband illumination from the illumination source to provide a selected filtered spectrum for broadband inspection.

19. The system of claim **18**, further comprising:

a controller communicatively coupled to the first motor and the additional motor, wherein the controller includes one or more processors configured to execute a set of program instructions, wherein the program instructions are configured to cause the one or more processors to control a rotational state of at least one of the first wheel or the additional wheel via at least one of the first motor or additional motor to achieve one or more selected spectral characteristics in the beam of broadband illumination.

20. The system of claim **18**, wherein the first plurality of filters includes 5 to 25 filters.

21. The system of claim **18**, wherein the additional plurality of filters includes 5 to 25 filters.

22. The system of claim **18**, wherein the illumination source is positioned off-axis relative to at least one of the rotational axis of the first wheel or the rotational axis of the second wheel.

23. The system of claim **18**, wherein the first plurality of filters includes at least one of a low pass filter or a high pass filter.

24. The system of claim **18**, wherein the additional plurality of filters includes at least one of a low pass filter or a high pass filter.

25. The system of claim **18**, wherein the illumination source configured to emit broadband illumination comprises at least one of a laser sustained plasma (LSP), a discharge broadband source, or a broadband laser.

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