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United States Patent	12392732
Kind Code	B2
Date of Patent	August 19, 2025
Inventor(s)	Zhang; Jian et al.

Multi-source illumination unit and method of operating the same

Abstract

An illumination unit comprising a first electromagnetic wave source including circuitry for outputting a first electromagnetic wave in a first direction to illuminate a first region of a sample; a second electromagnetic wave source including circuitry for outputting a second electromagnetic wave in a second direction substantially opposite to the first direction; and a reflector configured to reflect the second electromagnetic wave substantially in the first direction to illuminate a second region of the sample.

Inventors:	**Zhang; Jian (San Jose, CA), Wang; Yixiang (Fremont, CA), Kang; Zhiwen (Milpitas, CA)**
Applicant:	**ASML Netherlands B.V.** (Veldhoven, NL)
Family ID:	**1000008767401**
Assignee:	**ASML Netherlands B.V. (Veldhoven, NL)**
Appl. No.:	**17/283930**
Filed (or PCT Filed):	**September 20, 2019**
PCT No.:	**PCT/EP2019/075313**
PCT Pub. No.:	**WO2020/074238**
PCT Pub. Date:	April 16, 2020

Prior Publication Data

Document Identifier	**Publication Date**
US 20210396683 A1	Dec. 23, 2021

Related U.S. Application Data

us-provisional-application US 62744558 20181011

Publication Classification

Int. Cl.: **G01N21/95** (20060101); **G01N21/88** (20060101)

U.S. Cl.:

CPC **G01N21/9505** (20130101); **G01N21/8806** (20130101); G01N2021/8816 (20130101); G01N2021/8835 (20130101); G01N2021/8845 (20130101)

Field of Classification Search

CPC: G01N (21/8806); G01N (2021/8816); G01N (2021/8835); G01N (2021/8845); G01N (21/9505); G01N (2021/8812); G01N (21/9501); G03F (7/7065); G02F (1/13306); G02F (1/1334); G06T (2207/20081); G06T (2207/30108); G06T (7/0004); H01L (22/12); H04N (23/56)

USPC: 356/237.1-23; 356/239.1-23

References Cited

U.S. PATENT DOCUMENTS

Patent No.	Issued Date	Patentee Name	U.S. Cl.	CPC
4540278	12/1984	Phillips	N/A	N/A
5713661	12/1997	White	362/17	G01N 21/8806
2012/0147333	12/2011	Jorgensen	353/31	G03B 21/2033
2015/0092001	12/2014	Yoshida	347/118	G02B 26/127
2015/0338191	12/2014	Maryfield	345/633	F41G 3/00
2017/0082932	12/2016	Fu et al.	N/A	N/A
2019/0015930	12/2018	Berg	N/A	H01S 3/1643
2023/0168208	12/2022	Sun	348/92	H04N 23/56

FOREIGN PATENT DOCUMENTS

Patent No.	Application Date	Country	CPC
1685197	12/2004	CN	N/A
102472896	12/2011	CN	N/A
1968115	12/2007	EP	N/A
3348899	12/2017	EP	N/A
2004069612	12/2003	JP	N/A
2004164967	12/2003	JP	N/A
2006-162456	12/2005	JP	N/A
2006208258	12/2005	JP	N/A
2008-227494	12/2007	JP	N/A
2010182583	12/2009	JP	N/A

2012104296	12/2011	JP	N/A
2017-107201	12/2016	JP	N/A
6571900	12/2018	JP	F21K 9/65
200710589	12/2006	TW	N/A
WO 2017/115290	12/2016	WO	N/A

OTHER PUBLICATIONS

Office Action of the Intellectual Property Office issued in related Taiwan Patent Application No. 109143232; mailed Nov. 8, 2021 (14 pgs.). cited by applicant
Notice of Reasons for Rejection form the Japan Patent Office issued in related Japanese Patent Application No. 2021-515100; mailed May 23, 2022 (13 pgs.). cited by applicant
Taiwan Office Action issued in corresponding Application No. 108134336, mailed Jun. 15, 2020 (12 pages). cited by applicant
International search report in PCT Application No. PCT/EP2019/075313, mailed Nov. 12, 2019 (2 pages). cited by applicant
Notice of Reasons for Rejection from the Japan Patent Office issued in related Japanese Patent Application No. 2021-515100; mailed Aug. 14, 2023 (7 pgs.). cited by applicant

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Primary Examiner: Ton; Tri T

Attorney, Agent or Firm: Finnegan, Henderson, Farabow, Garrett & Dunner, LLP

Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) This application claims priority to International Application No. PCT/EP2019/075313, filed Sep. 20, 2019, and published as WO 2020/074238 A1, which claims priority of U.S. application 62/744,558 which was filed on Oct. 11, 2018. The contents of these applications are incorporated herein by reference in their entireties.

FIELD
(1) Apparatuses and methods consistent with the present disclosure relate generally to optics, and more particularly, to illumination units having two electromagnetic wave sources.
BACKGROUND
(2) An illumination unit is one of key components in optical systems for variety of applications, for example, semiconductor wafer inspection system, lithography system, projector system, biological sample imaging system, etc. An illumination unit comprising a light source such as a light emitting diode (LED) lamp or xenon lamp often provides a monotonic electromagnetic wave with a fixed field of view. Further improvements in the art are desired.
SUMMARY
(3) According to some embodiments of the present disclosure, there is provided an illumination unit. The illumination unit comprises a first electromagnetic wave source including circuitry for outputting a first electromagnetic wave in a first direction to illuminate a first region of a sample; a second electromagnetic wave source including circuitry for outputting a second electromagnetic wave in a second direction substantially opposite to the first direction; and a reflector configured to reflect the second electromagnetic wave substantially in the first direction to illuminate a second region of the sample.
(4) The illumination unit may further comprise a first controller including circuitry for controlling the first electromagnetic wave source; and a second controller including circuitry for controlling the second electromagnetic wave source, wherein the first controller and the second controller may

operate synergetic or independently.
(5) The illumination unit may further comprise a first moving mechanism controlled by the first controller to move the first electromagnetic wave source, and a second moving mechanism controlled by the second controller to move the second electromagnetic wave source, wherein at least one of the first moving mechanism and the second moving mechanism includes one of a servo motor, a robotic arm, a magnetic levitation system, and a magnetic force control system.
(6) The illumination unit may further comprise a first diffuser that faces an illumination surface of the first electromagnetic wave source and is configured to diffuse the first electromagnetic wave outputted from the first electromagnetic wave source, and a condenser that faces the first diffuser and collimates the first electromagnetic wave diffused through the first diffuser. A diameter of the reflector may be larger than a diameter of the first diffuser and the condenser may have substantially the same size as the first diffuser. The condenser and the first diffuser may be in contact.
(7) The illumination unit may further comprise a second diffuser that faces the reflector and is configured to diffuse the second electromagnetic wave reflected from the reflector. A size of the second diffuser may be larger than a size of the first diffuser. The first diffuser and the second diffuser may be made of the same material or different materials.
(8) The illumination unit may further comprise a projection lens configured to project at least one of the first diffuser and the second diffuser to a predetermined location, wherein a radius of the projection lens is substantially the same as a radius of the second diffuser.
(9) According to some embodiments of the present disclosure, there is provided an illumination unit, comprising: a first diffuser configured to diffuse a first electromagnetic wave from a first electromagnetic waver source onto a first region of a sample; and a second diffuser configured to diffuse a second electromagnetic wave from a second electromagnetic waver source onto a second region of the sample, wherein the first and second electromagnetic waves diffused from the first and second diffusers simultaneously illuminate the first and second regions of the sample. The first diffuser and the second diffuser may overlap each other. A size of the first diffuser may be smaller than a size of the second diffuser. The first diffuser may be placed in a concave portion of the second diffuser such that the first diffuser and the second diffuser are placed on the same plane. In some embodiments of the present disclosure, the first and second electromagnetic wave sources may be arranged in parallel such that the first and second electromagnetic waves originated from the first and second electromagnetic wave sources have the same propagation direction. In some embodiments of the present disclosure, the first and second electromagnetic wave sources may be arranged in the form of back-to-back and the illumination unit may further comprise a reflector that reflects the second electromagnetic wave to a direction substantially the same as a propagation direction of the first electromagnetic wave.
(10) According to some embodiments of the present disclosure, there is provided an illumination device, comprising: a first electromagnetic wave source including circuitry for outputting a first electromagnetic wave in a first direction; a second electromagnetic wave source including circuitry for outputting a second electromagnetic wave in a second direction opposite to the first direction; a first beam expander that faces the first electromagnetic wave source and is configured to expand the outputted first electromagnetic wave to provide an angle of field of view; a beam collimator that faces the first beam expander and is configured to collimate the expanded first electromagnetic wave; a beam reflector faces the second electromagnetic wave source and is configured to reflect the outputted second electromagnetic wave; and a second beam expander that faces the beam reflector and is configured to expand the reflected second electromagnetic wave to provide an angle of field of view. The illumination device may further comprise a projection lens configured to project at least one of the first beam expander and the second beam expander to a predetermined position.
(11) According to some embodiments of the present disclosure, there is provided a method for

illuminating a sample, comprising: outputting a first electromagnetic wave in a first direction to illuminate a first region of the sample; outputting a second electromagnetic wave in a second direction substantially opposite to the first direction; and reflecting the second electromagnetic wave substantially in the first direction to illuminate a second region of the sample.
(12) The method may further comprise: passing the first electromagnetic wave through a first beam expander; passing the expanded first electromagnetic wave through a collimator; and passing the reflected second electromagnetic wave through a second beam expander; and passing the collimated first electromagnetic wave and the expanded second electromagnetic wave through a projection lens.
(13) The subject matter below is taught by way of various specific exemplary embodiments explained in detail, and illustrated in the enclosed drawing figures. For the purpose of illustrating the invention, there is shown in the drawings a form that is presently preferred, however, the present invention is not limited to the precise arrangements and instrumentalities shown.

Description

BRIEF DESCRIPTION OF FIGURES
(1) FIG. **1** is a schematic diagram illustrating an exemplary illumination unit having two electromagnetic wave sources arranged in a form of back-to-back, consistent with some embodiments of the present disclosure.
(2) FIG. **2** is a schematic diagram illustrating a surface of a sample illuminated by the illumination unit of FIG. **1**, consistent with some embodiments of the present disclosure.
(3) FIG. **3** is a flowchart indicating an exemplary method of operating an illumination unit of FIG. **1**, consistent with some embodiments of the present disclosure.
(4) FIG. **4** is a schematic diagram illustrating another exemplary illumination unit having two electromagnetic wave sources arranged with the illumination surfaces facing at the same direction, consistent with some embodiments of the present disclosure.
(5) FIG. **5** is a schematic diagram illustrating wave transmitted through a diffuser, showing a working mechanism of a diffuser, consistent with some embodiments of the present disclosure.
(6) FIG. **6** is a flowchart indicating an exemplary method of operating an illumination unit of FIG. **4**, consistent with some embodiments of the present disclosure.
(7) FIG. **7** is a schematic diagram illustrating another exemplary illumination unit having two electromagnetic wave sources arranged in a form of back-to-back, consistent with some embodiments of the present disclosure.
(8) FIG. **8** is a flowchart indicating an exemplary method of operating an illumination unit of FIG. **7**, consistent with some embodiments of the present disclosure.
(9) FIG. **9** is a schematic diagram illustrating another exemplary illumination unit having two electromagnetic wave sources arranged in a form of back-to-back, consistent with some embodiments of the present disclosure.
(10) FIG. **10** is a flowchart indicating an exemplary method of operating an illumination unit of FIG. **9**, consistent with some embodiments of the present disclosure.
(11) FIG. **11** is a schematic diagram illustrating another exemplary illumination unit having two electromagnetic wave sources movable from each other, consistent with some embodiments of the present disclosure.
(12) FIG. **12** illustrates an exemplary arrangement of an imaging system utilizing an illumination unit having two electromagnetic wave sources, consistent with some embodiments of the present disclosure.
(13) FIG. **13** illustrates another exemplary arrangement of an imaging system utilizing an illumination unit having two electromagnetic wave sources, consistent with some embodiments of

the present disclosure.

DETAILED DESCRIPTION

(14) Reference will now be made in detail to exemplary embodiments, examples of which are illustrated in the accompanying drawings. The following description refers to the accompanying drawings in which the same numbers in different drawings represent the same or similar elements unless otherwise represented. The implementations set forth in the following description of exemplary embodiments do not represent all implementations consistent with the invention. Instead, they are merely examples of apparatuses and methods consistent with aspects related to the invention as recited in the appended claims. For example, although some embodiments are described in the context of utilizing visible light, the disclosure is not so limited. Other types of electromagnetic waves, for example, infrared, ultraviolet, x-rays, and fluorescent light be similarly applied.

(15) The enhanced computing power of electronic devices, while reducing the physical size of the devices, can be accomplished by significantly increasing the packing density of circuit components, such as transistors, capacitors, diodes, etc. on an integrated circuit (IC) chip. For example, in a smart phone, an IC chip (which is the size of a thumbnail) may include over 2 billion transistors, the size of each transistor being less than 1/1000th of a human hair. Not surprisingly, semiconductor IC manufacturing is a complex process, with hundreds of individual steps. Errors in even one step have the potential to dramatically affect the functioning of the final product. Even one “killer defect” can cause device failure. The goal of the manufacturing process is to improve the overall yield of the process. For example, for a 50-step process to get 75% yield, each individual step must have a yield greater than 99.4%, and if the individual step yield is 95%, the overall process yield drops to 7%.

(16) A killer defect can be any fatal damage or defect that occurs in various steps of the semiconductor manufacturing process, including macro/micro cracks or voids on a die, flip-chip underfill void, missing seal, delamination, voids in metal interconnect, and nanometer scale pattern defects, among others. As semiconductor device sizes continually become smaller and smaller (along with any defects), identifying defects becomes more challenging and costly. Currently, engineers in semiconductor manufacturing lines sometimes spend hours (and even days) to identify locations of small detects to minimize their impact on the final product.

(17) Optical imaging offers a large-scale, rapid, and non-destructive inspection method to identify many types of defects. To assist with identifying defects, conventional systems use light sources (e.g., illumination units) that emit light at a specific wavelength across a portion of a wafer, and capture wafer images for further analysis. A wafer to be imaged usually includes different areas having different light reflectivity. For example, in a semiconductor wafer, a metal deposition area may have a higher reflectivity than the area surrounding it. In this case, illuminating the semiconductor wafer with uniform light often results in a captured image having too much contrast; that is, the metal deposition area would be overexposed while the area surrounding would be underexposed. As another example, in a semiconductor wafer including uneven structures, peaks and valleys of the uneven structures may cast hard shadows while the area surrounding the uneven structures optimally reflect an incoming illumination light. The resulting poor quality images in turn cause difficulty or even failure in defect identification, which can decrease performance and reliability of manufactured semiconductor devices, or even can cause failures of the devices. These poor quality images also prolong post-imaging analysis processes, thereby decreasing efficiency of defect inspection and decreasing throughput.

(18) Some embodiments of the present disclosure provide multiple illumination arrangements that contribute to obtaining high quality wafer images, thereby improving accuracy and efficiency of defect identification, which in turn improves performance and reliability of the manufactured semiconductor devices as well as throughput. For example, the disclosed embodiments provide the ability to illuminate different areas of a sample simultaneously with different electromagnetic

waves or with different intensities of the same electromagnetic waves. By using these different illumination arrangements, the disclosed embodiments can minimize the effects of contrast and reduce hard shadows that would occur under convention systems. Moreover, the described embodiments provide the ability to adjust the illumination area or the angle of the field of view. By providing the ability to illuminate different areas of the sample simultaneously using multiple-intensity lights or multiple-wavelength lights, the quality of images is improved, which in turn causes the accuracy and efficiency of defect detection is improved, thereby leading to increased throughput.

(19) As used herein, unless specifically stated otherwise, the term "or" encompasses all possible combinations, except where infeasible. For example, if it is stated that a database may include A or B, then, unless specifically stated otherwise or infeasible, the database may include A, or B, or A and B. As a second example, if it is stated that a database may include A, B, or C, then, unless specifically stated otherwise or infeasible, the database may include A, or B, or C, or A and B, or A and C, or B and C, or A and B and C.

(20) References are now made to FIG. **1**, a schematic diagram illustrating an exemplary illumination unit having two electromagnetic wave sources arranged in a form of back-to-back, consistent with some embodiments of the present disclosure. As shown in FIG. **1**, an illumination unit **100** comprises a first electromagnetic wave source including an illumination surface **112**, a wave generator **110** and a controller **104**. Wave generator **110** includes circuitry configured to generate a first electromagnetic wave by various methods, for example, by transforming chemical energy into electromagnetic waves. An electromagnetic wave **116** generated from wave generator **110** is emitted through illumination surface **112** and propagates in the forward direction. Controller **104** may control an intensity of electromagnetic wave **116** by controlling wave generator **110**, for example, by adjusting a current supplying to the wave generator. Controller **104** may be a component included in the wave generator **110**, or a detached component connected to wave generator **110** by a wire or a wireless remote component (not shown) that controls wave generator **110** by a wireless remote signal such as an infrared signal, a radio signal, a WIFI signal, or any telecommunication signals.

(21) Illumination unit **100** may further comprise a second electromagnetic wave source including an illumination surface **106**, a wave generator **108** and a controller **102**. Wave generator **108** includes circuitry configured to generate a second electromagnetic wave by various methods, for example, by transforming electrical energy into second electromagnetic waves. An electromagnetic wave **118** generated from wave generator **108** is emitted through illumination surface **106** and propagates in a backward direction. Controller **102** may control an intensity of electromagnetic wave **118** by controlling wave generator **108**, for example, by adjusting a current supplying to wave generator **108**. Wave generator **110** and wave generator **108** may be arranged in a form of back-to-back, that is, wave generator **110** and wave generator **108** are adjacent to each other while illumination surfaces **106** and **112** are spaced apart from each other by wave generators **110** and **108**, and illumination surfaces **106** and **112** are facing different directions, e.g., backward and forward directions, respectively.

(22) In some embodiments of the present disclosure, the first electromagnetic wave source and the second electromagnetic wave source may be the same type or different types of electromagnetic wave sources. For example, without limiting the embodiments of the present disclosure, the first electromagnetic wave source may be an organic light emitting diode type while the second electromagnetic wave source may be an inorganic light emitting diode type. A bandwidth of the first electromagnetic wave may be the same as or different from a bandwidth of the second electromagnetic wave. The bandwidths of the first and second electromagnetic waves may be narrow or broad. In some embodiments of the present disclosure, a type of the first or second electromagnetic wave sources may be an inorganic light emitting diode (LED), an organic light emitting diode (OLED), a cold cathode fluorescent lamp, a plasma lamp, a tungsten lamp, a xenon

lamp, a mercury arc lamp, or a mercury-xenon discharge lamp, among others. The first and second electromagnetic wave sources may have the same size or different sizes. The intensity of the first electromagnetic wave may be the same as or different from the intensity of the second electromagnetic wave, depending on a control manner of controllers **102** and **104**, either synergetic or independently, among others.

(23) Illumination unit **100** further comprises a reflector **114** configured to collimate electromagnetic wave **118** transmitted from the second electromagnetic wave source. A reflection surface of reflector **114** may be a curved mirror such that an incoming electromagnetic wave with various incident angles can be reflected on the surface of the curved mirror to form a substantially parallel electromagnetic wave propagating substantially in the forward direction. In some embodiments, a "substantially parallel electromagnetic wave" means that a deviation of the reflected electromagnetic wave from parallel is less than ±15°, and "substantially in the forward direction" means that a deviation of the reflected electromagnetic wave from the forward direction is less than ±15°. In some embodiments of the present disclosure, a radius of reflector **114** may be two times of a distance between reflector **114** and the second electromagnetic wave source. Reflector **114** is not limited to a curved mirror and can be any collimator or device that can change propagation direction of an electromagnetic wave. Moreover, reflector **114** can filter certain electromagnetic waves so that only those traveling parallel or substantially parallel to a certain direction (the forward direction in this case) are allowed through. By collimating the second electromagnetic wave into the forward direction, illumination unit **100** may substantially simultaneously illuminate a sample **122** with the first electromagnetic wave and the second electromagnetic wave. One skilled in the art would understand that the two electromagnetic waves substantially simultaneously illuminating the sample may include any delay in propagation and detection of the electromagnetic waves and any delay in controlling the illumination units. In some embodiments of the present disclosure, controllers **102** and **104** may control the onset time of output of electromagnetic waves **118** and **116** by controlling wave generators **108** and **110**, respectively, such that there is a controlled duration between the output of electromagnetic wave **118** and the output of electromagnetic wave **116**.

(24) References are now made to FIG. **2**, a schematic diagram illustrating a surface of a sample illuminated by the illumination unit of FIG. **1**, consistent with some embodiments of the present disclosure. As shown in FIG. **2**, a surface **200** of a sample includes a region **202** that is illuminated by the first electromagnetic wave, and a region **204** that is illuminated by the second electromagnetic wave. Region **202** and region **204** may be illuminated by two different electromagnetic waves, for example, region **202** may be illuminated by fluorescent light while region **204** is illuminated by white light, or may be illuminated by same electromagnetic waves, for example, white light. Region **202** and region **204** may be illuminated by the same electromagnetic wave having different intensities, for example, region **202** may be illuminated with a high-intensity light while region **204** is illuminated with a low-intensity light. Using the illumination unit of FIG. **1**, two different regions of a sample can be observed or imaged differently, under the illumination with two different electromagnetic waves.

(25) References are now made to FIG. **3**, a flowchart indicating an exemplary method of operating an illumination unit as shown in FIG. **1**, consistent with some embodiments of the present disclosure. In FIG. **3**, steps S**302** and S**304** describe the steps of operating the first electromagnetic wave source. In step S**302**, the first electromagnetic wave is emitted from the first electromagnetic wave source, such as wave generator **110** of FIG. **1**, and transmitted in the forward direction, as is electromagnetic wave **116**. The first electromagnetic wave may be a narrow bandwidth or a broad bandwidth electromagnetic wave, among others. In step S**304**, the first electromagnetic wave outputs into a first region of a sample, such as region **202** of FIG. **2**. In FIG. **3**, steps S**306** and S**308** describe the steps of operating the second electromagnetic wave source. In step S**306**, the second electromagnetic wave, such as wave **118** of FIG. **1**, is emitted from the second electromagnetic

wave source, such as wave generator **108**, and is transmitted in the backward direction to impinge onto a reflector, such as reflector **114** of FIG. **1**. In step S**308**, the second electromagnetic wave reflected and collimated by the reflector, propagates in the forward direction, and outputs into a second region of the sample, such as region **204** of FIG. **2**. As a result, in step S**310**, the first region of the sample is illuminated by the first electromagnetic wave, while the second region of the sample is illuminated by the second electromagnetic wave. In some embodiments of the present disclosure, the first and second electromagnetic waves may substantially simultaneously illuminate the first region and the second region of the sample. One skilled in the art would understand that the two electromagnetic waves substantially simultaneously illuminating the first and second region of the sample may include any delay in propagation and detection of the electromagnetic waves and any delay in controlling the illumination units. In some embodiments of the present disclosure, the onset times of output of the first and second electromagnetic waves are controlled such that there is a controlled duration between the output of the first electromagnetic wave and the output of the second electromagnetic wave.

(26) References are now made to FIG. **4**, a schematic diagram illustrating another exemplary illumination unit having two electromagnetic wave sources arranged with the illumination surfaces facing at the same direction, consistent with some embodiments of the present disclosure. As shown in FIG. **4**, an illumination unit **400** comprises a first electromagnetic wave source including an illumination surface **414**, a wave generator **412** and a controller **404**. Wave generator **412** includes circuitry configured to generate a first electromagnetic wave by various methods, for example, by transforming a chemical energy into electromagnetic waves. An electromagnetic wave **416** generated from the wave generator **412** is emitted through illumination surface **414** and propagates in the forward direction. Controller **404** may control intensity of electromagnetic wave **416** by controlling wave generator **412**, for example, by adjusting a current supplying to the wave generator **412**. Controller **404** may be a component included in the wave generator **412**, or a detached component connected to wave generator **412** by a wire or a wireless remote component (not shown) that controls wave generator **412** by a remote signal such as an infrared signal, radio signal, a WIFI signal, or any telecommunication signal.

(27) In some embodiments, illumination unit **400** further comprises a diffuser **418** that faces illumination surface **414** of the first electromagnetic wave source. Diffuser **418** is configured to diffuse the incoming electromagnetic wave **418** transmitted from the first electromagnetic wave source. In some embodiments of the present disclosure, diffuser **418** may be any beam expander that faces illumination surface **414** of the first electromagnetic wave source and is configured to expand electromagnetic wave **418** to provide a desired field of view. The working mechanism of a diffuser is schematically shown in FIG. **5**. As shown in FIG. **5**, when electromagnetic wave **502** enters a diffuser **504**, the electromagnetic wave is redistributed due to the scattering of the electromagnetic wave in the diffuser. The scattered electromagnetic wave with a certain scattering angle (as shown as θ angle) occupies the maximum intensity, and electromagnetic wave intensity decreases with the increase of the scattering angle θ. A full viewing angle of diffuser **504** may be defined by the electromagnetic wave with a scattering angle where the intensity of the electromagnetic wave decreases to 50% of a maximum intensity of the electromagnetic wave.

(28) Referring back to FIG. **4**, illumination unit **400** further comprises a second electromagnetic wave source including an illumination surface **408**, a wave generator **406** and a controller **402**. Wave generator **406** includes circuitry configured to generate a second electromagnetic wave by various methods, for example, by transforming an electrical energy into the second electromagnetic wave. An electromagnetic wave **410** generated from the wave generator **406** is emitted through illumination surface **408** and propagates in the forward direction. Controller **402** may control an intensity of electromagnetic wave **410** by controlling wave generator **406**, for example, by adjusting a current supplying to the wave generator.

(29) In some embodiments, illumination unit **400** further comprises a diffuser **420** that faces

illumination surface **408** of the second electromagnetic wave source. Diffuser **420** is configured to diffuse the incoming electromagnetic wave **410** transmitted from the second electromagnetic wave source. A size of diffuser **420** may be greater than a size of diffuser **418**. Diffuser **418** and diffuser **420** may overlap each other. Diffuser **418** may be placed in a concave portion of diffuser **420** such that diffuser **418** and diffuser **420** are placed on the same plane. Diffuser **418** and diffuser **420** may be made of the same material or different materials.

(30) Electromagnetic wave **416** diffused through diffuser **418** merges with electromagnetic wave **410** diffused through diffuser **420** to form a large illumination area. And, diffuser **420** may be selected to have a viewing angle smaller than that of diffuser **418**, as schematically shown by scattering angle of diffused electromagnetic waves **422** and **424**. In this way, illumination unit **400** can provide a large illumination area with small angle of field of view. Also, diffuser **420** and diffuser **418** may be selected from different materials having different degree of light scattering such that diffused electromagnetic waves **422** and **424** have different qualities (e.g., softness/hardness). For example, diffuser **418** may be selected to have a degree of light scattering higher than that of diffuser **420** such that a light diffused through diffuser **418** is soft light while a light diffused through diffuser **420** is a hard light. In this way, illumination unit **400** can provide two different electromagnetic waves having different levels of softness/hardness.

(31) References are now made to FIG. **6**, a flowchart indicating an exemplary method of operating an illumination unit as shown in FIG. **4**, consistent with some embodiments of the present disclosure. In FIG. **6**, steps S**602** and S**604** describe the steps of operating the first electromagnetic wave source. In step S**602**, the first electromagnetic wave, such as electromagnetic wave **416** of FIG. **4**, is emitted from the first electromagnetic wave source, such as wave generator **412** of FIG. **4**, and transmitted in the forward direction. The first electromagnetic wave may be a narrow bandwidth or a broad bandwidth electromagnetic wave, among others. In step S**604**, the first electromagnetic wave enters a first diffuser, such as diffuser **418** of FIG. **4**, and the diffused first electromagnetic wave illuminates a first region of a sample.

(32) In FIG. **6**, steps S**606** and S**608** describe the steps of operating the second electromagnetic wave source. In step S**606**, the second electromagnetic wave, such as electromagnetic wave **410**, is emitted from the second electromagnetic wave source, such as wave generator **406**, and transmitted in the forward direction. The second electromagnetic wave may be a narrow bandwidth or a broad bandwidth electromagnetic wave, among others. In step S**608**, the second electromagnetic wave enters a second diffuser, such as diffuser **420**, and the diffused second electromagnetic wave illuminates a second region of a sample. In some embodiments, the first region and the second region overlap, while in other embodiments, they do not overlap. As a result, in step S**610**, the first region of the sample is illuminated by the diffused first electromagnetic wave, while the second region of the sample is illuminated by the diffused second electromagnetic wave. The second diffuser may be selected to have a viewing angle smaller than that of the first diffuser, in this way, the sample may have a large illumination area with small angle of field of view. The second diffuser may be selected to have a degree of scattering smaller than that of the first diffuser. In this way, the sample may be illuminated by two electromagnetic waves having two different levels of softness, in this case, a softer first electromagnetic wave is surrounded by a harder second electromagnetic wave, which may partially or entirely overlap the first electromagnetic wave.

(33) References are now made to FIG. **7**, a schematic diagram illustrating an exemplary illumination unit having two electromagnetic wave sources arranged in a form of back-to-back, consistent with some embodiments of the present disclosure. As shown in FIG. **7**, an illumination unit **700** comprises a first electromagnetic wave source including an illumination surface **718**, a wave generator **716** and a controller **704**. Wave generator **716** includes circuitry configured to generate a first electromagnetic wave by various methods, for example, by transforming a chemical energy into an electromagnetic wave. An electromagnetic wave **720** generated by wave generator **716** is emitted through illumination surface **718** and propagates in the forward direction. Controller

704 may control an intensity of electromagnetic wave **720** by controlling wave generator **716**, for example, by adjusting a current supplying to wave generator **716**. Controller **704** may be a component included in the wave generator **716**, or a detached component connected to wave generator **716** by a wire, or a wireless remote component (not shown) that controls wave generator **716** by a remote signal such as an infrared signal, a radio signal, a WIFI signal or any telecommunication signal.

(34) In some embodiments, illumination unit **700** further comprises a diffuser **722** that faces illumination surface **718** of the first electromagnetic wave source. Diffuser **722** is configured to diffuse the incoming electromagnetic wave **720** transmitted from the first electromagnetic wave source.

(35) Illumination unit **700** may further comprise a second electromagnetic wave source including an illumination surface **712**, a wave generator **714** and a controller **702**. Wave generator **714** includes circuitry configured to generate a second electromagnetic wave by various methods, for example, by transforming an electrical energy into the second electromagnetic wave. An electromagnetic wave **708** generated by wave generator **714** is emitted through illumination surface **712** and propagates in the backward direction. Controller **702** may control an intensity of electromagnetic wave **708** by controlling wave generator **714**, for example, by adjusting a current supplying to the wave generator. Wave generator **714** and wave generator **716** may be arranged in the form of previously defined back-to-back configuration.

(36) In some embodiments of the present disclosure, the first electromagnetic wave source and the second electromagnetic wave source may be the same type or different types of electromagnetic wave sources. A bandwidth of the first electromagnetic wave may be the same as or different from a bandwidth of the second electromagnetic wave. The bandwidths of the first and second electromagnetic waves may be narrow or broad. In some embodiments of the present disclosure, a type of the first and second electromagnetic wave sources may be an inorganic light emitting diode (LED), an organic light emitting diode (OLED), a cold cathode fluorescent lamp, a plasma lamp, a tungsten lamp, a xenon lamp, a mercury arc lamp, or a mercury-xenon discharge lamp, among others. The first and second electromagnetic wave sources may have the same size or different sizes. The intensity of the first electromagnetic wave may be the same as or different from the intensity of the second electromagnetic wave, depending on a manner of controllers **102** and **104**, either synergetic or independently, among others.

(37) Illumination unit **700** further comprises a reflector **706** configured to reflect and collimate electromagnetic wave **708** transmitted from the second electromagnetic wave source. A reflection surface of reflector **706** may be a curved mirror such that an incoming electromagnetic wave with various incident angles can be reflected on the surface of the curved mirror to form a parallel electromagnetic wave propagating in forward direction. Reflector **706** is not limited to a curved mirror, it can be any collimator or device that can change propagation direction of an electromagnetic wave or can filter certain electromagnetic waves so that only those traveling parallel or substantially parallel to a certain direction (the forward direction in this case) are allowed through.

(38) Illumination unit **700** further comprises a diffuser **724** that faces reflector **706**. Diffuser **724** is configured to diffuse the incoming reflected second electromagnetic wave **710**. A size of diffuser **724** may be greater than a size of diffuser **722**. A size of diffuser may be similar to a size of reflector **706**. Diffuser **722** and diffuser **724** may overlap each other. Diffuser **722** may be placed in a concave portion of diffuser **724** such that diffuser **722** and diffuser **724** are placed on the same plane. Diffuser **722** and diffuser **724** may be made of the same material or different materials. Electromagnetic wave **720** diffused through diffuser **722** merges with electromagnetic wave **710** diffused through diffuser **724** to form a large illumination area. And, diffuser **724** may be selected to have a viewing angle smaller than that of diffuser **722**, as schematically shown by scattering angle of diffused electromagnetic waves **726** and **728**. In this way, illumination unit **700** can

provide a large illumination area with small angle of field of view. Also, diffuser **722** and diffuser **724** may be selected from different materials having different degree of light scattering such that diffused electromagnetic waves **726** and **728** have different qualities (e.g., softness/hardness). For example, diffuser **724** may be selected to have a degree of light scattering higher than that of diffuser **722** such that a light diffused through diffuser **724** is soft light while a light diffused through diffuser **722** is a hard light. In this way, illumination unit **700** can provide two different electromagnetic waves having different levels of softness/hardness.

(39) References are now made to FIG. **8**, a flowchart indicating an exemplary method of operating an illumination unit as shown in FIG. **7**, consistent with some embodiments of the present disclosure. In FIG. **8**, steps S**802** and S**804** describe the steps of operating the first electromagnetic wave source. In step S**802**, the first electromagnetic wave, such as electromagnetic wave **720** of FIG. **7**, is emitted from the first electromagnetic wave source, such as wave generator **716** of FIG. **7**, and is transmitted in the forward direction. The first electromagnetic wave may be a narrow bandwidth or a broad bandwidth electromagnetic wave, among others. In step S**804**, the first electromagnetic wave enters a first diffuser, such as diffuser **722** of FIG. **7**, and the diffused first electromagnetic wave illuminates a first region of a sample.

(40) In FIG. **8**, steps S**806**-S**810** describe the steps of operating the second electromagnetic wave source. In step S**806**, the second electromagnetic wave, such as electromagnetic wave **708** of FIG. **7**, is emitted from the second electromagnetic wave source and transmitted in the backward direction. The second electromagnetic wave may be a narrow bandwidth or a broad bandwidth electromagnetic wave, among others. In step S**808**, the second electromagnetic wave is reflected and collimated by a reflector and propagates in the forward direction. In step S**810**, the reflected second electromagnetic wave enters a second diffuser, such as diffuser **724** of FIG. **7**, and the diffused second electromagnetic wave illuminates a second region of a sample. As a result, in step S**812**, the first region of the sample is illuminated by the diffused first electromagnetic wave, while the second region of the sample is illuminated by the diffused second electromagnetic wave (e.g., such as shown in FIG. **2**). Second diffuser may be selected to have a viewing angle smaller than that of the first diffuser. In this way, the sample may have a large illumination area with small angle of field of view. The second diffuser may be selected to have a degree of scattering smaller than that of the first diffuser. In this way, the sample may be illuminated by two electromagnetic waves having two different levels of softness, in this case, a softer first electromagnetic wave is surrounded by a harder second electromagnetic wave.

(41) References are now made to FIG. **9**, a schematic diagram illustrating an exemplary illumination unit having two electromagnetic wave sources arranged in the form of the previously defined back-to-back configuration, consistent with some embodiments of the present disclosure. As shown in FIG. **9**, an illumination unit **900** comprises a first electromagnetic wave source including an illumination surface **918**, a wave generator **916** and a controller **904**. Wave generator **916** includes circuitry configured to generate a first electromagnetic wave by various methods, for example, by transforming a chemical energy into electromagnetic wave. An electromagnetic wave **920** generated by wave generator **916** is emitted through illumination surface **918** and propagates in the forward direction. Controller **904** may control intensity of electromagnetic wave **920** by controlling wave generator **916**, for example, by adjusting a current supplying to the wave generator. Controller **904** may be a component included in the wave generator **916**, or a detached component connected to wave generator **916** by a wire, or a wireless remote component (not shown) that controls wave generator **916** by a remote signal.

(42) In some embodiments, illumination unit **900** further comprises a diffuser **922** that faces illumination surface **918** of the first electromagnetic wave source. Diffuser **922** is configured to diffuse the incoming electromagnetic wave **920** transmitted from the first electromagnetic wave source. In some embodiments of the present disclosure, diffuser **922** and illumination surface **918** may have circular shapes having substantially the same radius. Here, “substantially the same

radius” means that there may be up to ±10% difference in a radius of diffuser **922** and a radius of illumination surface **918**.

(43) Illumination unit **900** further comprises a condenser **928** that faces diffuser **922**. Condenser **928** is configured to collimate incoming electromagnetic wave transmitted through diffuser **922**. Condenser **928** may be an optical collimator such as a lens, but not limited to a lens. Condenser **928** can be any collimator or device that can change propagation direction of electromagnetic wave or can filter certain electromagnetic wave so that only those traveling parallel or substantially parallel to a certain direction (forward direction in this case) are allowed through. Condenser **928** is not limited to an optical collimator; it may be any element or device configured to converge incoming electromagnetic wave transmitted through diffuser **922**. Condenser **928** may provide both collimating and converging function at the same time. Condenser **928** and diffuser **922** may be in contact or spaced apart from each other. Condenser **928** may have a size substantially the same as or different from a size of diffuser **922**. Here, “substantially the same” means that there may be up to ±10% difference in the size of condenser **928** and the size of diffuser **922**.

(44) Illumination unit **900** further comprises a second electromagnetic wave source including an illumination surface **912**, a wave generator **914** and a controller **902**. Wave generator **914** includes circuitry configured to generate a second electromagnetic wave by various methods, for example, by transforming an electrical energy into the second electromagnetic wave. An electromagnetic wave **908** generated by wave generator **914** is emitted through illumination surface **912** and propagates in the backward direction. Controller **902** may control intensity of electromagnetic wave **908** by controlling wave generator **914**, for example, by adjusting a current supplying to the wave generator. Wave generator **914** and wave generator **916** may be arranged in the form of back-to-back in which the wave generators that completely overlap or partially overlap.

(45) In some embodiments of the present disclosure, the first electromagnetic wave source and the second electromagnetic wave source may be the same type or different types of electromagnetic wave sources. A bandwidth of the first electromagnetic wave may be the same as or different from a bandwidth of the second electromagnetic wave. The bandwidths of the first and second electromagnetic waves may be narrow or broad, among others. In some embodiments of the present disclosure, a type of the first and second electromagnetic wave sources may be an inorganic light emitting diode (LED), an organic light emitting diode (OLED), a cold cathode fluorescent lamp, a plasma lamp, a tungsten lamp, a xenon lamp, a mercury arc lamp, or a mercury-xenon discharge lamp, among others. The first and second electromagnetic wave sources may have the same size or different sizes. The intensity of the first electromagnetic wave may be the same as or different from the intensity of the second electromagnetic wave, depending on a manner of controllers **102** and **104**, either synergetic or independently.

(46) Illumination unit **900** further comprises a reflector **906** configured to collimate electromagnetic wave **908** transmitted from the second electromagnetic wave source. A reflection surface of reflector **906** may be a curved mirror such that an incoming electromagnetic wave with various incident angles can be reflected on the surface of the curved mirror to form a parallel electromagnetic wave propagating in forward direction. Reflector **906** is not limited to a curved mirror; it can be any collimator or device that can change propagation direction of an electromagnetic wave or can filter certain electromagnetic waves so that only those traveling parallel or substantially parallel to a certain direction (forward direction in this case) are allowed through.

(47) Illumination unit **900** further comprises a diffuser **924** that faces reflector **906**. Diffuser **924** is configured to diffuse the incoming reflected second electromagnetic wave **910**. A size of diffuser **924** may be greater than a size of diffuser **922**. A size of diffuser **924** may be similar to a size of reflector **906**. Diffuser **922** and diffuser **924** may overlap each other. Diffuser **922** may be placed in a concave portion of diffuser **924** such that diffuser **922** and diffuser **924** are placed on the same plane. Diffuser **922** and diffuser **924** may be made of the same material or different materials.

(48) The first electromagnetic wave emitted from the first electromagnetic wave source is collimated or converged by condenser **928**. Also, before condenser **928**, the first electromagnetic wave transmitted through diffuser **922** and redistributed by the diffuser. In this way, a relatively small illumination area with large angle of field of view can be obtained. Electromagnetic wave **920** transmitted through diffuser **922** and condenser **928** merges with electromagnetic wave **910** diffused through diffuser **924** to form a large illumination area. And, diffuser **924** may be selected to have a viewing angle smaller than that of diffuser **922**, as schematically shown by scattering angles of diffused electromagnetic waves **926** and **930**. In this way, illumination unit **900** can provide a large illumination area with small angle of field of view. Electromagnetic wave **930** illuminates a first area of a sample and electromagnetic wave **926** illuminates a second area of the sample. The first area and the second area may overlap, or may not overlap.
(49) Diffuser **922** and diffuser **924** may be selected from different materials having different degree of light scattering such that diffused electromagnetic waves **926** and **928** have different qualities (e.g., softness/hardness). For example, diffuser **924** may be selected to have a degree of light scattering higher than that of diffuser **922** such that a light diffused through diffuser **924** is soft light while a light diffused through diffuser **922** is a hard light. In this way, illumination unit **900** can provide two different electromagnetic waves having different levels of softness/hardness.
(50) Controller **902** and controller **904** may operate synergistically or independently. Controller **902** and controller **904** may control the luminous flux of the two electromagnetic wave sources, respectively. By tuning their respective control circuits, the available luminous flux into the image system for illumination can be balanced for different fields of view.
(51) The two electromagnetic wave sources may operate at the same time. When the first electromagnetic wave source is switched off while keeping the second electromagnetic wave source on, the illumination unit gives a ring shape illumination. In this way, the illumination unit behaves like a dark field mode, which indicates that the high frequency feature is activated while low frequency feature is inactivated. Contrast of an image can be enhanced in such an illumination mode.
(52) By way of example, in some embodiments of the present disclosure, a green LED with a wavelength ranging between 515-575 nm is used for the first and second electromagnetic wave sources. The viewing angle of the LED at 50% relative luminous intensity is about 120o, while the viewing angle at 85% relative luminous intensity is about 60o. In order to make the illumination in the full field of view relatively uniform, the 60o viewing angle may be used. With the thermal sink, the LED size may be Φ=10 mm. For an illumination in the forward direction, a diffuser **922** with size of Φ=10 mm is placed in front of illumination surface **918**. A separation distance between illumination surface **918** and diffuser **922** is about 8.66 mm. Following diffuser **922**, a collector lens **928** with effective focal length of about 8.66 mm is used such that the light from illumination surface **918** is diffused through diffuser **922** and collimated by collector lens **928**. Diffuser **922** has a uniform scattering light angle of ±30o. In this way, for the illumination in the forward direction, an illumination area of Φ=10 mm with an angle of field of view of 30o may be achieved.
(53) On the other hand, for an illumination in the backward direction, the 60o viewing angle of illumination surface **912** is also used. A reflector **906** is placed in front of illumination surface **912**. A separation distance between reflector **906** and illumination surface **912** is about 30 mm. The radius of curvature of reflector **906** is about 60 mm. The light from LED source **2** is collimated by reflector **906** and propagates in the forward direction. A diffuser **924** facing reflector **906** is placed such that light collimated by reflector **906** is diffused through diffuser **924**. Diffuser **924** is contacted and concentric with diffuser **922**. Diffuser **924** has a size of Φ=30 mm, and its uniform scattering light angle is about ±10o. In this way, for the illumination in backward direction, an illumination area of Φ=30 mm with an angle of field of view of 10o may be achieved.
(54) Illumination unit **900** may further comprise a projection lens **932** that projects the electromagnetic wave originated from the two electromagnetic wave sources, consistent with some

embodiments of the present disclosure. Projection lens **932** may direct the incoming electromagnetic wave to a specific location, depending on a magnification of the lens. When the back focal plane of condenser **928** does not overlap with the diffusers, a projection lens with appropriate magnification factor can be used to conjugate the diffusers onto the back focal plane of the condenser. The magnification factor can be tuned by changing the distance between the projection lens and the diffusers.

(55) References are now made to FIG. **10**, a flowchart indicating an exemplary method of operating an illumination unit having two electromagnetic wave sources as shown in FIG. **9**, consistent with some embodiments of the present disclosure. In FIG. **10**, steps S**1001** to S**1004** describe the steps of operating the first electromagnetic wave source. In step S**1001**, a first electromagnetic wave, such as electromagnetic wave **920** of FIG. **9**, is emitted from a first electromagnetic wave source and transmitted to a first diffuser, such as diffuser **922** of FIG. **9**, in the forward direction. The first electromagnetic wave source may be a narrow bandwidth or a broad bandwidth electromagnetic wave, among others. The first diffuser redistributes the incoming first electromagnetic wave by a scattering mechanism. The scattered first electromagnetic wave with a certain scattering angle occupies the maximum intensity, and electromagnetic wave intensity decreases with an increase of the scattering angle. In step S**1002**, the diffused first electromagnetic wave is passed through a condenser, such as condenser **928** of FIG. **9**, facing the first diffuser. The condenser may collect the first electromagnetic wave by collimating or converging the diffused first electromagnetic wave in the forward direction. In step S**1003**, as an option, the collected first electromagnetic wave passes through a projection lens, such projection lens **932** in FIG. **9**. In step S**1004**, the first electromagnetic wave transmitted through the projection lens is output onto a first region of a sample.

(56) In FIG. **10**, steps S**1005** to S**1008** describe the steps of operating the second electromagnetic wave source. In step S**1005**, a second electromagnetic wave, such as electromagnetic wave **908** of FIG. **9**, is emitted from a second electromagnetic wave source in the backward direction and reaches to a reflector, such as reflector **906** of FIG. **9**. The backward direction is opposite to the forward direction. The reflector changes the propagation direction of the second electromagnetic wave to the forward direction and collimates the second electromagnetic wave. A type of the second electromagnetic wave may be the same as or different from the type of the first electromagnetic wave. In step S**1006**, the reflected second electromagnetic wave is passed through a second diffuser, such as diffuser **924** of FIG. **9**, facing the reflector. The second diffuser redistributes the reflected second electromagnetic wave by scattering mechanism. In step S**1007**, as an option, the diffused second electromagnetic wave is passed through the projection lens. In step S**1008**, the second electromagnetic waves outputted onto a second region of the sample. In step S**1009**, as a result of the operations of steps S**1001-1008**, the first electromagnetic wave and the second electromagnetic wave may simultaneously illuminate two different regions of the sample. For example, the first region may be illuminated by red light in electromagnetic spectrum while the second region may be illuminated by blue light in electromagnetic spectrum. The first region and the second region may be illuminated by the same electromagnetic wave having different intensities. For example, the first region may be illuminated with high intensity light while the second region is illuminated with low intensity light. The first and second regions may overlap or may not overlap. Also, by selecting different combinations of the first and second diffusers, the illumination method can provide various illumination areas having various angles of field of views or various quality of electromagnetic waves.

(57) References are now made to FIG. **11** a schematic diagram illustrating an exemplary illumination unit having two electromagnetic wave sources movable from each other, consistent with some exemplary embodiments of the present disclosure. As shown in FIG. **11**, an illumination unit **1100** comprises a first electromagnetic wave source **1134** including an illumination surface **1118**, a driver **1116** and a controller **1104**. Driver **1116** includes circuitry configured to generate a

first electromagnetic wave, for example, by transforming a type of energy into an electromagnetic wave **1120** that emitted through illumination surface **1118**. Controller **1104** may control intensity of electromagnetic wave **1120** by controlling driver **1116**. Driver **1116** further includes a first moving mechanism configured to move the first electromagnetic wave source in the forward-backward direction. The first moving mechanism may comprise a servo motor or a robotic arm or a magnetic levitation system or a magnetic force control system, among others. Controller **1104** may control a direction and a speed of the movement by controlling the circuitry of the first moving mechanism.

(58) Illumination unit **1100** further comprises a second electromagnetic wave source **1132** including an illumination surface **1112**, a driver **1114** and a controller **1102**. Driver **1114** includes circuitry configured to generate a second electromagnetic wave **1108**. Generated second electromagnetic wave **1108** emits through illumination surface **1112**. Controller **1102** may control an intensity of electromagnetic wave **1108** by controlling driver **1114**. Driver **1114** further includes a second moving mechanism configured to move second electromagnetic wave source **1132** in the forward-backward direction. The second moving mechanism may comprise a servo motor or a robotic arm or a magnetic levitation system or a magnetic force control system, among others. The first and second moving mechanisms may be the same or different. Controller **1102** may control a direction and a speed of the movement by controlling the circuitry of the second moving mechanism. The first and second electromagnetic wave sources are arranged in the form of back-to-back in which the first and second electromagnetic wave sources completely overlap or partially overlap each other. Controllers **1102** and **1104** may be included in drivers **1114** and **1116**, respectively, or may be separated from drivers **1114** and **1116**.

(59) In some embodiments, illumination unit **1100** further comprises diffuser **1122**, condenser **1126**, reflector **1106**, diffuser **1124** and, optionally, a projection lens (not shown, similar to projection lens **932** in FIG. **9**). The function of diffuser **1122**, condenser **1126**, reflector **1106**, diffuser **1124** and the projection lens are similar to the function of diffuser **922**, condenser **928**, reflector **906**, diffuser **924** and projection lens **932**, as shown in FIG. **9**, and for brevity, detailed descriptions are omitted here. Electromagnetic wave **1110** diffused through diffuser **1124** merges with electromagnetic wave transmitted through condenser **1126** to form a large illumination area. Diffuser **1124** may be selected to have an angle of field of view smaller than that of diffuser **1122**. Electromagnetic wave **1128** illuminates a first area of a sample and electromagnetic wave **1130** illuminates a second area of the sample. In this case, the second area surrounds the first area. The first and second illumination areas may be adjusted by moving the electromagnetic wave sources, for example, moving electromagnetic waver source **1132** towards reflector **1106** may increase the second illumination area and moving electromagnetic waver source **1132** towards diffuser **1122** may decrease the second illumination area. In this way, an illumination area or an angle of field of view may be instantly adjusted according to a requirement of a system. The first and second illumination areas may overlap or may not overlap.

(60) References are now made to FIG. **12**, an exemplary arrangement of an imaging system utilizing an illumination unit having two electromagnetic wave sources, consistent with some embodiments of the present disclosure. As shown in FIG. **12**, an imaging system **1200** comprises an illumination unit **1202** having two electromagnetic wave sources, consistent with any one of the above described embodiments. Illumination unit **1202** is used as an illumination unit of the imaging system. Imaging system **1200** further comprises an objective lens **1208**, a tube lens **1204**, and a tube lens **1206**, and two beam splitters **1210** and **1212**. Beam splitters **1210** and **1212** may be made from two triangular glass prisms or a metal-coated mirror or a dichroic mirrored prism, among others. Beam splitter **1210** is configured to split an electromagnetic wave **1230** emitted from illumination unit **1202** into an electromagnetic wave **1232** and an electromagnetic wave **1234**. Electromagnetic wave **1232** enters tube lens **1206** and electromagnetic wave **1234** enters beam splitter **1212**. Beam splitter **1212** is configured to further split electromagnetic wave **1234** into an electromagnetic wave **1236** and an electromagnetic wave **1238**, that enter tube lens **1204** and

objective lens **1208**, respectively. Objective lens **1208** may be a common objective. Tube lens **1204** may include a lens **1214** having a large focal length for a high magnification imaging system. Tube lens **1206** may include a lens **1218** having a small focal length for a low magnification imaging system. The electromagnetic waves transmitted through tube lens **1204**, tube lens **1206**, and objective lens **1208** illuminate samples **1216**, **1220**, and **1228**, respectively. The illumination units disclosed in some embodiments of the present disclosure can be used in such an imaging system including high, normal, and low magnifications because it takes into account both small and large fields of view and adaptive adjustment of illumination area and field of view.

(61) For example, as illustrated in the example of imaging system **1200** as shown in FIG. **12**, common objective **1208** may be an objective with effective focal length about 85 mm and infinity corrected. Tube lens **1204** for a high magnification imaging system may be a lens with effective focal length about 215 mm. An object space NA (numerical aperture) of about 0.12 and a field of view of Φ=2.4 mm may be achieved. Tube lens **1206** for a low magnification image system may be a lens with effective focal length about 42.5 mm. The object space NA of about 0.026 and field of view of Φ=12 mm may be achieved. In this way, and by using illumination units disclosed in the present disclosure, an imaging system that covers high, normal, and low magnifications can be achieved with the help of beam splitters **1210** and **1212**.

(62) References are now made to FIG. **13**, an exemplary arrangement of an imaging system utilizing an illumination unit having two electromagnetic wave sources, consistent with some embodiments of the present disclosure. As shown in FIG. **13**, an imaging system **1300** comprises an illumination unit **1302** having two electromagnetic wave sources, consistent with any one of the above described embodiments. Illumination unit **1302** is used as an illumination unit of the system. Imaging system **1300** further comprises arrays of lenses M, N, and K. Each array of lenses may comprise a plurality of lenses. In FIG. **13**, array M comprises a plurality of common objectives, shown as objective **1304** . . . objective **1310**; array N comprises a plurality of high magnification lenses, shown as lens **1314** . . . lens **1318**; and array K comprises a plurality of low magnification lenses, shown as lens **1320** . . . lens **1328**. Imaging system **1300** further comprises two beam splitters **1350** and **1360**. Beam splitter **1350** splits electromagnetic wave emitted from illumination unit **1302** into two electromagnetic waves entering objective **1304** of the array M and beam splitter **1360**, respectively. Beam splitter **1360** further splits electromagnetic wave transmitted from beam splitter **1350** into two electromagnetic waves that enter objectives **1320** of array K and objective **1318** of array N, respectively. The electromagnetic waves transmitted through the arrays of objectives M, N, and K illuminate samples **1342**, **1340**, and **1336**, respectively. The illumination units disclosed in some embodiments of the present application can be used in such image systems because it takes into account both small and large field of view and adaptive adjustment of illumination area and field of view.

(63) The embodiments may further be described using the following clauses:

(64) 1. An illumination unit, comprising: a first electromagnetic wave source including circuitry for outputting a first electromagnetic wave in a first direction to illuminate a first region of a sample; a second electromagnetic wave source including circuitry for outputting a second electromagnetic wave in a second direction substantially opposite to the first direction; and a reflector configured to reflect the second electromagnetic wave substantially in the first direction to illuminate a second region of the sample.

(65) 2. The illumination unit of clause 1, further comprising: a first controller including circuitry for controlling the first electromagnetic wave source; and a second controller including circuitry for controlling the second electromagnetic wave source, wherein the first controller and the second controller operate independently.

(66) 3. The illumination unit of clause 2, further comprising: a first moving mechanism controlled by the first controller to move the first electromagnetic wave source in the first direction.

(67) 4. The illumination unit of any one of clauses 2 to 3, further comprising: a second moving

mechanism controlled by the second controller to move the second electromagnetic wave source in the second direction.
(68) 5. The illumination unit of any one of clauses 3 to 4, wherein the first moving mechanism or the second moving mechanism includes a servo motor, a robotic arm, a magnetic levitation system, or a magnetic force control system.
(69) 6. The illumination unit of clause 5, wherein the first moving mechanism or the second moving mechanism including a servo motor, a robotic arm, a magnetic levitation system, or a magnetic force control system includes the first moving mechanism and the second moving mechanism including one or more of a servo motor, a robotic arm, a magnetic levitation system, or a magnetic force control system.
(70) 7. The illumination unit of any one of clauses 1 to 6, further comprising: a first diffuser that faces an illumination surface of the first electromagnetic wave source and that is configured to diffuse the first electromagnetic wave outputted from the first electromagnetic wave source.
(71) 8. The illumination unit of clause 7, wherein a diameter of the reflector is larger than a diameter of the first diffuser.
(72) 9. The illumination unit of any one of clauses 7 to 8, further comprising: a condenser that faces the first diffuser and collimates the first electromagnetic wave diffused through the first diffuser.
(73) 10. The illumination unit of clause 9, wherein the condenser and the first diffuser are in contact.
(74) 11. The illumination unit of any one of clauses 9 to 10, wherein the condenser has substantially the same size as the first diffuser.
(75) 12. The illumination unit of any one of clauses 7 to 11, further comprising: a second diffuser that faces the reflector and is configured to diffuse the second electromagnetic wave reflected from the reflector.
(76) 13. The illumination unit of clause 12, wherein a size of the second diffuser is larger than a size of the first diffuser.
(77) 14. The illumination unit of any one of clauses 12 to 13, wherein the first diffuser and the second diffuser are made of the same material.
(78) 15. The illumination unit of any one of clauses 12 to 13, wherein the first diffuser and the second diffuser are made of different materials.
(79) 16. The illumination unit of any one of clauses 7 to 15, further comprising: a projection lens configured to project at least one of the first diffuser and the second diffuser to a predetermined location.
(80) 17. The illumination unit of clause 16, wherein a radius of the projection lens is substantially the same as a radius of the second diffuser.
(81) 18. The illumination unit of any one of clauses 1 to 17, wherein the first electromagnetic wave source and the second electromagnetic wave source are arranged back to back.
(82) 19. The illumination unit of any one of clauses 1 to 18, wherein the first electromagnetic wave and the second electromagnetic wave are a same type of electromagnetic wave.
(83) 20. The illumination unit of any one of clauses 1 to 18, wherein the first electromagnetic wave and the second electromagnetic wave are different types of electromagnetic waves.
(84) 21. The illumination unit of any one of clauses 1 to 20, wherein at least one of the first electromagnetic wave and the second electromagnetic wave is a broadband electromagnetic wave.
(85) 22. The illumination unit of any one of clauses 1 to 21, wherein a radius of the reflector is substantially two times of a distance between the reflector and the second electromagnetic wave source.
(86) 23. The illumination unit of any one of clauses 1 to 21, wherein the first region and the second region do not overlap each other.
(87) 24. The illumination unit of any one of clauses 1 to 21, wherein the first region and the second region partially overlap each other.

(88) 25. An illumination unit, comprising: a first diffuser configured to diffuse a first electromagnetic wave from a first electromagnetic waver source onto a first region of a sample; and a second diffuser configured to diffuse a second electromagnetic wave from a second electromagnetic waver source onto a second region of the sample, wherein the first and second electromagnetic waves diffused from the first and second diffusers simultaneously illuminate the first and second regions of the sample.
(89) 26. The illumination unit of clause 25, wherein the first diffuser and the second diffuser overlap each other.
(90) 27. The illumination unit of any one of clauses 25 to 26, wherein a size of the first diffuser is smaller than a size of the second diffuser.
(91) 28. The illumination unit of clause 25, wherein the first diffuser is placed in a concave portion of the second diffuser such that the first diffuser and the second diffuser are placed on the same plane.
(92) 29. The illumination unit of any one of clauses 25 to 28, further comprising: a reflector that reflects the second electromagnetic wave to a direction substantially the same as a propagation direction of the first electromagnetic wave.
(93) 30. An imaging system using the illumination unit of any one of clauses 1 to 29 as an illumination source.
(94) 31. The imaging system of clause 30, further comprising: at least two tube-lenses having different numerical apertures.
(95) 32. The imaging system of any one of clauses 30 to 31, further comprising: at least two tube-lenses having different fields of view.
(96) 33. The imaging system of clause 30, wherein: the imaging system comprises a plurality of imaging systems; at least one of the plurality of imaging systems comprises at least two tube-lenses having different numerical apertures; and the first electromagnetic wave and the second electromagnetic wave reach the plurality of imaging systems by passing through at least one beam splitter.
(97) 34. An illumination device, comprising: a first electromagnetic wave source including circuitry for outputting a first electromagnetic wave in a first direction; a second electromagnetic wave source including circuitry for outputting a second electromagnetic wave in a second direction substantially opposite to the first direction; a first beam expander that faces the first electromagnetic wave source and is configured to expand the outputted first electromagnetic wave to provide a first angle of field of view; a beam collimator that faces the first beam expander and is configured to collimate the expanded first electromagnetic wave; a beam reflector faces the second electromagnetic wave source and is configured to reflect the outputted second electromagnetic wave; and a second beam expander that faces the beam reflector and is configured to expand the reflected second electromagnetic wave to provide a second angle of field of view.
(98) 35. The illumination device of clause 34, further comprising: a projection lens configured to project at least one of the first beam expander and the second beam expander to a predetermined position.
(99) 36. An imaging system using the illumination device of any one of clauses 34 to 35 as an illumination source.
(100) 37. A method for illuminating a sample, comprising: outputting a first electromagnetic wave in a first direction to illuminate a first region of the sample; outputting a second electromagnetic wave in a second direction substantially opposite to the first direction; and reflecting the second electromagnetic wave substantially in the first direction to illuminate a second region of the sample.
(101) 38. The method of clause 37, further comprising: passing the first electromagnetic wave through a first beam expander.
(102) 39. The method of clause 38, further comprising: passing the expanded first electromagnetic

wave through a collimator; and passing the reflected second electromagnetic wave through a second beam expander.
(103) 40. The method of clause 39, further comprising: passing the collimated first electromagnetic wave and the expanded second electromagnetic wave through a projection lens.
(104) While the previously mentioned embodiments are directed to illuminating a sample, the described embodiments could be used in other fields. For example, in life science and medical studies, physiological parameters (e.g., blood flow, oxygen consumption, concentration of tissue metabolites such as hemoglobin) can be measured by determining optical property of tissues, for example, by measuring an absorption of a light at one or more wavelengths by the tissues. It is desirable to be able to simultaneously gather different physiological data, for example, simultaneously monitoring in real time of tissue parameters such as tissue oxygenation and total blood volume, using different light wavelengths.
(105) Example embodiments are described above with reference to flowchart illustrations or block diagrams of methods, apparatus (systems) and computer program products. It will be understood that each block of the flowchart illustrations or block diagrams, and combinations of blocks in the flowchart illustrations or block diagrams, can be implemented using computer program instructions (e.g., by passing instructions to the various controllers shown in FIGS. **1**, **4**, **7**, **9**, and **11**). These computer program instructions may be provided to a processor of a computer, or other programmable data processing apparatus to produce a machine, such that the instructions, which execute via the processor of the computer or other programmable data processing apparatus, create means for implementing the functions/acts specified in the flowchart or block diagram block or blocks.
(106) These computer program instructions may also be stored in a computer readable medium that can direct a hardware processor core of a computer, other programmable data processing apparatus, or other devices to function in a particular manner, such that the instructions stored in the computer readable medium form an article of manufacture including instructions that implement the function/act specified in the flowchart or block diagram block or blocks.
(107) The computer program instructions may also be loaded onto a computer, other programmable data processing apparatus, or other devices to cause a series of operational steps to be performed on the computer, other programmable apparatus or other devices to produce a computer implemented process such that the instructions which execute on the computer or other programmable apparatus provide processes for implementing the functions/acts specified in the flowchart or block diagram block or blocks.
(108) Any combination of one or more computer readable medium(s) may be utilized. The computer readable medium may be a non-transitory computer readable storage medium. A computer readable storage medium may be, for example, but not limited to, an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system, apparatus, or device, or any suitable combination of the foregoing. More specific examples (a non-exhaustive list) of the computer readable storage medium would include the following: an electrical connection having one or more wires, a portable computer diskette, a hard disk, a random access memory (RAM), a read-only memory (ROM), an erasable programmable read-only memory (EPROM, EEPROM or Flash memory), an optical fiber, a portable compact disc read-only memory (CD-ROM), an optical storage device, a magnetic storage device, or any suitable combination of the foregoing. In the context of this document, a computer readable storage medium may be any tangible medium that can contain, or store a program for use by or in connection with an instruction execution system, apparatus, or device.
(109) Program code embodied on a computer readable medium may be transmitted using any appropriate medium, including but not limited to wireless, wireline, optical fiber cable, RF, IR, etc., or any suitable combination of the foregoing.
(110) Computer program code for carrying out operations for example embodiments may be

written in any combination of one or more programming languages, including an object-oriented programming language such as Java, Smalltalk, C++ or the like and conventional procedural programming languages, such as the “C” programming language or similar programming languages.
(111) The flowchart and block diagrams in the Figures illustrate examples of the architecture, functionality, and operation of possible implementations of systems, methods and computer program products according to various embodiments. It should also be noted that, in some alternative implementations, the functions noted in the block may occur out of the order noted in the figures. For example, two blocks shown in succession may, in fact, be executed substantially concurrently, or the blocks may sometimes be executed in the reverse order, depending upon the functionality involved.
(112) It is understood that the described embodiments are not mutually exclusive, and elements, components, materials, or steps described in connection with one example embodiment may be combined with, or eliminated from, other embodiments in suitable ways to accomplish desired design objectives.
(113) Reference herein to “some embodiments” or “some exemplary embodiments” mean that a particular feature, structure, or characteristic described in connection with the embodiment can be included in at least one embodiment. The appearance of the phrases “one embodiment” “some embodiments” or “some exemplary embodiments” in various places in the specification do not all necessarily refer to the same embodiment, nor are separate or alternative embodiments necessarily mutually exclusive of other embodiments.
(114) It should be understood that the steps of the example methods set forth herein are not necessarily required to be performed in the order described, and the order of the steps of such methods should be understood to be merely example. Likewise, additional steps may be included in such methods, and certain steps may be omitted or combined, in methods consistent with various embodiments.
(115) As used in this application, the word “exemplary” is used herein to mean serving as an example, instance, or illustration. Any aspect or design described herein as “exemplary” is not necessarily to be construed as preferred or advantageous over other aspects or designs. Rather, use of the word is intended to present concepts in a concrete fashion.
(116) Unless explicitly stated otherwise, each numerical value and range should be interpreted as being approximate as if a word such as “about” or “approximately” or the like preceded the value of the value or range.
(117) The use of figure numbers or figure reference labels in the claims is intended to identify one or more possible embodiments of the claimed subject matter to facilitate the interpretation of the claims. Such use is not to be construed as necessarily limiting the scope of those claims to the embodiments shown in the corresponding figures.
(118) Although the elements in the following method claims, if any, are recited in a particular sequence with corresponding labeling, unless the claim recitations otherwise imply a particular sequence for implementing some or all of those elements, those elements are not necessarily intended to be limited to being implemented in that particular sequence.
(119) It will be further understood that various changes in the details, materials, and arrangements of the parts which have been described and illustrated in order to explain the nature of described embodiments may be made by those skilled in the art without departing from the scope as expressed in the following claims.

Claims

1. An illumination unit, comprising: a first electromagnetic wave source including circuitry for outputting a first electromagnetic wave in a first direction to illuminate a first region of a sample; a

second electromagnetic wave source including circuitry for outputting a second electromagnetic wave in a second direction substantially opposite to the first direction; and a reflector configured to reflect and collimate the second electromagnetic wave substantially in the first direction to illuminate a second region of the sample.

2. The illumination unit of claim 1, further comprising: a first controller including circuitry for controlling the first electromagnetic wave source; and a second controller including circuitry for controlling the second electromagnetic wave source, wherein the first controller and the second controller operate independently.

3. The illumination unit of claim 2, further comprising: a first moving mechanism controlled by the first controller to move the first electromagnetic wave source in the first direction.

4. The illumination unit of claim 2, further comprising: a second moving mechanism controlled by the second controller to move the second electromagnetic wave source in the second direction.

5. The illumination unit of claim 4, wherein the first moving mechanism or the second moving mechanism includes a servo motor, a robotic arm, a magnetic levitation system, or a magnetic force control system.

6. The illumination unit of claim 5, wherein the first moving mechanism or the second moving mechanism including a servo motor, a robotic arm, a magnetic levitation system, or a magnetic force control system includes the first moving mechanism and the second moving mechanism including one or more of a servo motor, a robotic arm, a magnetic levitation system, or a magnetic force control system.

7. The illumination unit of claim 1, further comprising: a first diffuser that faces an illumination surface of the first electromagnetic wave source and that is configured to diffuse the first electromagnetic wave outputted from the first electromagnetic wave source.

8. The illumination unit of claim 7, wherein a diameter of the reflector is larger than a diameter of the first diffuser.

9. The illumination unit of claim 7, further comprising: a condenser that faces the first diffuser and collimates the first electromagnetic wave diffused through the first diffuser.

10. The illumination unit of claim 9, wherein the condenser and the first diffuser are in contact.

11. The illumination unit of claim 9, wherein the condenser has substantially the same size as the first diffuser.

12. The illumination unit of claim 7, further comprising: a second diffuser that faces the reflector and is configured to diffuse the second electromagnetic wave reflected from the reflector.

13. The illumination unit of claim 12, wherein a size of the second diffuser is larger than a size of the first diffuser.

14. The illumination unit of claim 12, wherein the first diffuser and the second diffuser are made of the same material.

15. A method for illuminating a sample, comprising: outputting a first electromagnetic wave in a first direction to illuminate a first region of the sample; outputting a second electromagnetic wave in a second direction substantially opposite to the first direction; and reflecting and collimating the second electromagnetic wave substantially in the first direction to illuminate a second region of the sample.

16. A non-transitory computer readable medium that stores a set of instructions that is executable by at least on processor of a computing device to cause the computing device to perform operations for illuminating a sample, the operations comprising: causing emission of a first electromagnetic wave in a first direction to illuminate a first region of the sample; causing emission of a second electromagnetic wave in a second direction substantially opposite to the first direction; and causing reflection and collimation of the second electromagnetic wave substantially in the first direction to illuminate a second region of the sample.

17. The non-transitory computer readable medium of claim 16, wherein the operations further comprise controlling a first moving mechanism to move the first electromagnetic wave in the first

direction.

18. The non-transitory computer readable medium of claim 17, wherein the operations further comprise controlling a second moving mechanism to move the second electromagnetic wave in the second direction.

19. The non-transitory computer readable medium of claim 18, wherein controlling the first moving mechanism or controlling the second moving mechanism includes controlling one of a servo motor, a robotic arm, a magnetic levitation system, or a magnetic force control system.