US 20140055830A1

(19) United States
(12) Patent Application Publication
PYUN et al.
(10) Pub. No.: US 2014/0055830 A1
(43) Pub. Date: Feb. 27, 2014

(54) PHASE MASK AND HOLOGRAPHIC RECORDING APPARATUS EMPLOYING THE SAME

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(21) Appl. No.: **14/010,858**

(22) Filed: **Aug. 27, 2013**

(30) **Foreign Application Priority Data**

Aug. 27, 2012 (KR) 10-2012-0093885

Publication Classification

(51) **Int. Cl.**
G03H 1/04 (2006.01)
G02B 5/32 (2006.01)
G02B 5/30 (2006.01)

(52) **U.S. Cl.**
CPC ***G03H 1/041*** (2013.01); ***G02B 5/3083*** (2013.01); ***G03H 1/0406*** (2013.01); ***G02B 5/32*** (2013.01)
USPC **359/15**; 359/486.01; 359/30; 359/31

(57) **ABSTRACT**

A phase mask includes a phase modulation layer that modulates a phase of different portions of incident light, differently, such that a different optical phase delay, in a range between 0 and 2π is imparted to different portions of the incident light. A hologram recording apparatus includes a light source; a signal beam optical system that divides a beam emitted from the light source into a reference beam and a signal beam, modulates the signal beam according to hologram pixel information, and radiates the signal beam onto a hologram recording medium. The signal beam optical system includes the phase mask. The hologram recording apparatus also includes a reference beam optical system that radiates the reference beam onto the hologram recording medium.

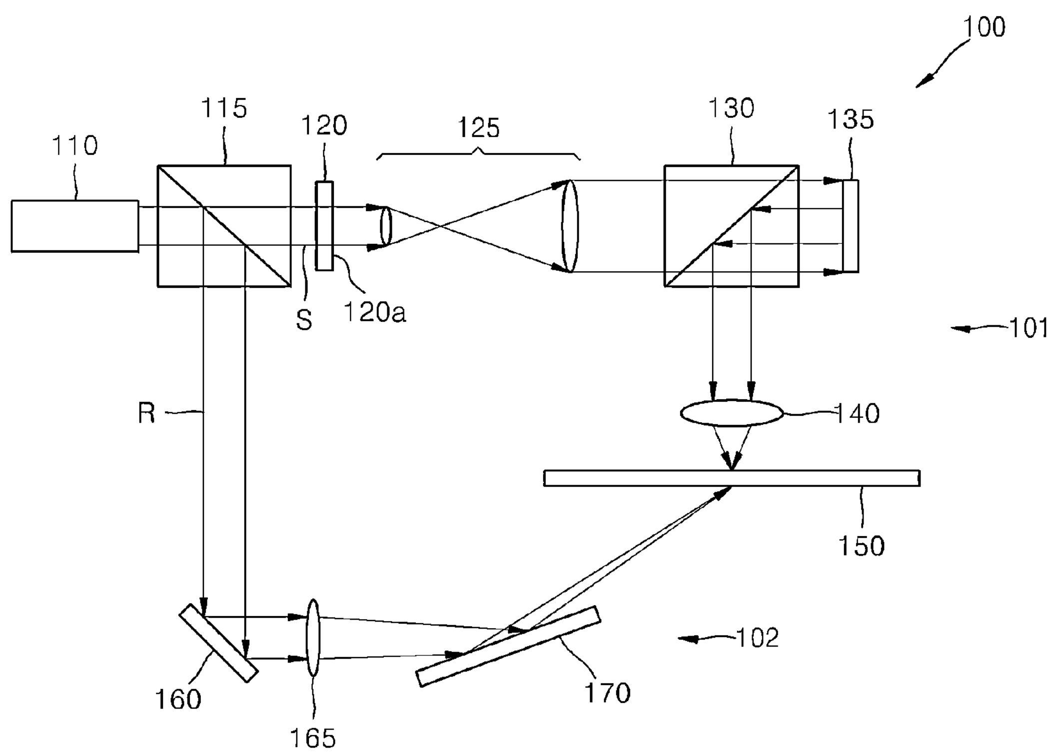


FIG. 1

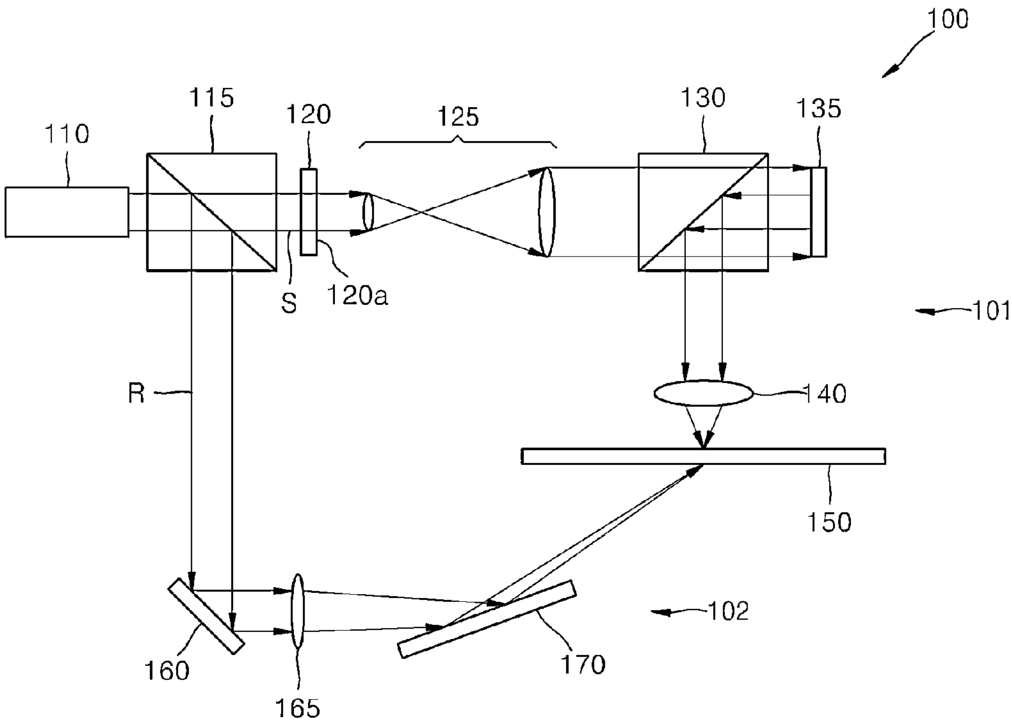

100
115
120
125
130
135
110
S
120a
101
R
140
150
102
160
165
170

FIG. 2

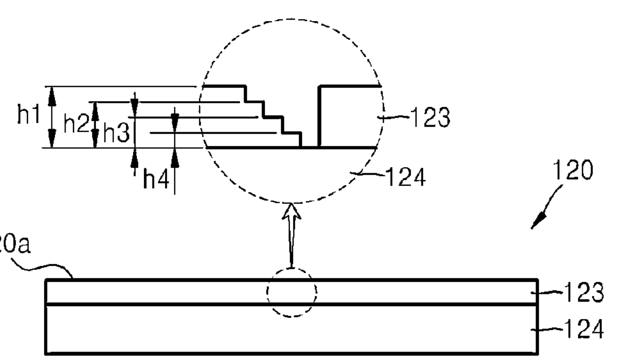

h1
h2
h3
h4
123
124
120
120a
123
124

FIG. 3

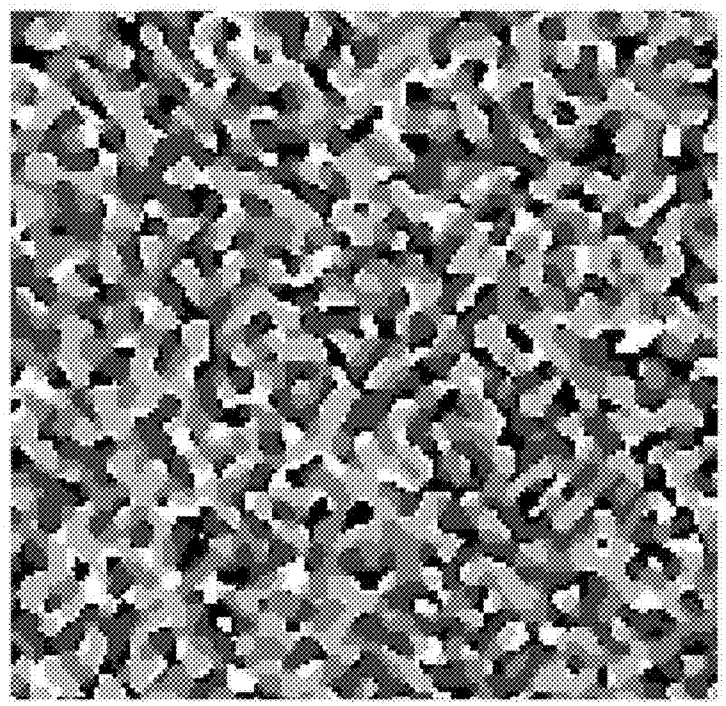


FIG. 4

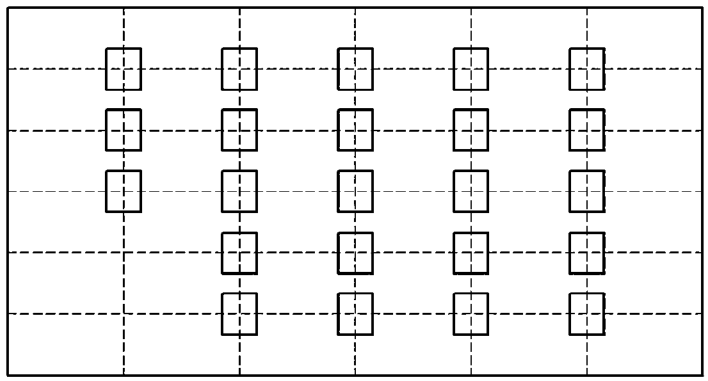
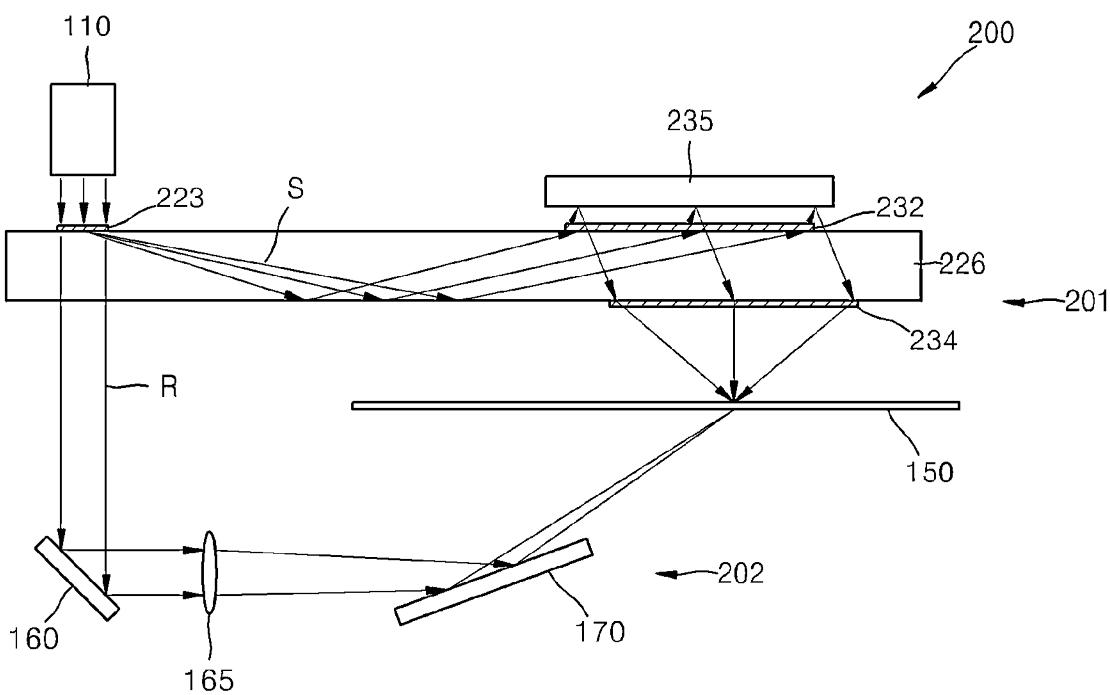


FIG. 5



PHASE MASK AND HOLOGRAPHIC RECORDING APPARATUS EMPLOYING THE SAME

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority from Korean Patent Application No. 10-2012-0093885, filed on Aug. 27, 2012, in the Korean Intellectual Property Office, the disclosure of which is incorporated herein in its entirety by reference.

BACKGROUND

[0002] 1. Field

[0003] Apparatuses consistent with exemplary embodiments relate to a hologram recording technology with an improved uniformity of a hologram.

[0004] 2. Description of the Related Art

[0005] Hologram technology is a technology by which a signal can be reproduced as a stereo-scopic image by recording interference fringes between a signal beam and a reference beam. Hologram technology may be used in various ways, for example, to record and reproduce a stereo-scopic image, prevent counterfeiting, identify a genuine product, and record and reproduce digital data. Also, micro hologram technology, by which minute interference fringes are recorded on a flat plate type photosensitive recording film in pixel units to display a three-dimensional (3D) image on a two-dimensional (2D) plane is being commercialized.

[0006] In order to record a hologram, various factors, for example, optimization of light efficiency, the generation of a hogel (hologram pixel) with a desired shape, the maximization of a fill factor of a hogel, the reduction in recording time, insensitiveness to an angular selectivity when reproducing a hologram, etc. should be considered. Also, these factors should be realized without decreasing a display quality.

SUMMARY

[0007] One or more exemplary embodiments provide a hologram recording apparatus with an improved uniformity of a hologram.

[0008] Additional exemplary aspects and advantages will be set forth in part in the description which follows and, in part, will be apparent from the description, or may be learned by practice of the presented embodiments.

[0009] According to an aspect of an exemplary embodiment, a phase mask includes: a phase modulation layer that differently modulates a phase of incident light, wherein an optical phase delay occurs spatially randomly in a range between 0 and 2π.

[0010] The phase modulation layer may be formed of a transparent material and has a non-uniform thickness having a value between 0 and $n\lambda$, wherein n denotes a refractive index of the transparent material and λ denotes a wavelength of incident light.

[0011] The phase modulation layer may have N thicknesses different from each other by location, and the N thicknesses of the phase modulation layer are uniformly distributed, wherein N denotes a natural number.

[0012] An angular spectrum of transmitted light may have a quadrilateral shape.

[0013] The phase modulation layer may be formed of a photoresist.

[0014] The phase modulation layer may have a non-uniform thickness by using a photolithography process, and a diffusing angle may be determined according to an incident angle of a beam that is shaped for exposure.

[0015] The phase mask may further include a glass substrate that supports the phase modulation layer.

[0016] According to an aspect of another exemplary embodiment, a hologram recording apparatus includes a light source; a signal beam optical system that divides a beam emitted from the light source into a reference beam and a signal beam, modulates the divided signal beam according to hologram pixel information, and radiates the modulated signal beam onto a hologram recording medium, wherein the signal beam optical system includes the phase mask of claim **1**; and a reference beam optical system that radiates the reference beam onto the hologram recording medium.

[0017] The signal beam optical system may include: a beam splitting extension portion that divides the light emitted from the light source into the reference beam and the signal beam and extends a diameter of the signal beam; the phase mask; a spatial light modulator that modulates the signal beam based on hologram pixel information; and an object lens unit that focuses the signal beam modulated by the spatial light modulator on the hologram recording medium.

[0018] The beam splitting extension portion may include: a first beam splitter that divides the light emitted from the light source into the reference beam and the signal beam; and a pair of relay lenses disposed on a light path of the signal beam.

[0019] The spatial light modulator may be a reflective spatial light modulator.

[0020] The hologram recording apparatus may further include a second beam splitter that is disposed between the beam extension portion and the object lens unit and divides light in such a way that light emitted from the beam extension portion is directed to the spatial light modulator and light modulated by the spatial light modulator is directed to the object lens unit.

[0021] The beam splitting extension portion, the second beam splitter, and the object lens unit include first, second, and third holographic optical elements, respectively.

[0022] The phase mask may be integrally formed in any one of the first, second, and third holographic optical elements.

[0023] Any one of the first, second, and third holographic optical elements may be configured in such a way that a diffraction grating pattern appropriate for a function to be performed is formed in the phase mask.

[0024] The phase mask may be disposed adjacent to any one of the first, second, and third holographic optical elements.

[0025] A light guide member, for guiding light by total reflection, may further be disposed between the light source and the hologram recording medium.

[0026] The first, second, and third holographic optical elements may be disposed on the light guide member.

[0027] The reference beam optical system may include an object lens for focusing the reference beam on the hologram recording medium, and at least one minor for adjusting a light path.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028] These and/or other exemplary aspects and advantages will become apparent and more readily appreciated from the following description of exemplary embodiments, taken in conjunction with the accompanying drawings of which:

[0029] FIG. **1** a schematic view of a hologram recording apparatus according to an exemplary embodiment;

[0030] FIG. **2** is a view showing a detailed structure of a phase mask used in the hologram recording apparatus of FIG. **1**;

[0031] FIG. **3** is an image showing light intensity distribution of a cross-section of a beam passing through the phase mask of FIG. **1** according to an exemplary embodiment;

[0032] FIG. **4** is a diagram showing several positions sampled to measure uniformity, after a white patch is recorded using the hologram recording apparatus of FIG. **1**, according to an exemplary embodiment; and

[0033] FIG. **5** is a schematic view of a hologram recording apparatus according to another exemplary embodiment.

DETAILED DESCRIPTION

[0034] Reference will now be made in detail to embodiments, examples of which are illustrated in the accompanying drawings, wherein like reference numerals refer to the like elements throughout. In this regard, the present embodiments may have different forms and should not be construed as being limited to the descriptions set forth herein. Accordingly, the embodiments are merely described below, by referring to the figures, to explain aspects of the present description. Expressions such as "at least one of," when preceding a list of elements, modify the entire list of elements and do not modify the individual elements of the list.

[0035] FIG. **1** a schematic view of a hologram recording apparatus **100** according to an exemplary embodiment. FIG. **2** is a view showing a detailed structure of a phase mask **120** used in the hologram recording apparatus **100** of FIG. **1**. FIG. **3** is an image showing light intensity distribution of a cross-section of a beam passing through the phase mask **120** according to an exemplary embodiment.

[0036] Referring to FIG. **1**, the hologram recording apparatus **100** includes a light source **110**, a signal beam optical system **101** that divides a beam emitted from the light source **110** into a reference beam R and a signal beam S, modulates the divided signal beam according to hologram pixel information, and radiates the modulated signal beam onto a hologram recording medium **150**, and a reference beam optical system **102** that radiates the reference beam onto the hologram recording medium **150**.

[0037] The hologram recording apparatus **100** of the current embodiment uses the phase mask **120** for improving uniformity of a recorded hologram. The phase mask **120** is used to improve uniformity of a hologram and increase a fill factor of a hogel (hologram pixel). In other words, the phase mask **120** employs a structure in which an angular spectrum is formed to have a quadrilateral shape and an optical phase delay occurs spatially randomly.

[0038] Referring to FIG. **2**, the phase mask **120** includes a phase modulation layer **123**, and a top surface **120*a*** of the phase modulation layer **123** is non-uniform. The phase mask **120** includes the phase modulation layer **123** to modulate a phase of incident light with a wavelength of, for example, λ, by location. In other words, depending on the location of the phase mask **120** on which the incident light is incident, the phase of the light will be modulated differently. As shown in FIG. **2**, a thickness of the phase modulation layer **123** is not uniform. Also, as shown in FIG. **2**, the phase mask **120** may further include a glass substrate **124** that supports the phase modulation layer **123**, and a height from a top surface of the glass substrate **124** to the top surface **120*a*** of the phase modulation layer **123** is random.

[0039] A phase modulation layer **123** is formed of a transparent material, for example, a photoresist. The phase modulation layer **123** may have a non-uniform thickness varying between 0 and nλ, where a refractive index of the transparent material forming the phase modulation layer **121** is 'n'. For example, the phase modulation layer **123** may have N different thicknesses in different locations, and the N thicknesses of the phase modulation layer **123** may be uniformly distributed over the phase mask **120**, wherein N denotes a natural number.

[0040] FIG. **2** shows the phase modulation layer **123** with five different thicknesses. In other words, the height from the top surface of the glass substrate **124** to the top surface **120*a*** of the phase modulation layer **123** has any of five different heights: 0, h1, h2, h3, and h4. The heights h1, h2, h3, and h4 may be nλ/4, nλ/2, (3nλ)/4, and nλ, respectively. The phase modulation layer **123** has different heights to uniformly distribute light incident on the phase mask **120** into five phases of 0, π/4, π/2, (3π)/2, and 2π and delay the phase of the incident light accordingly. However, the number of a phase delay angle may vary in different ways.

[0041] The phase modulation layer **123** may have the above-described non-uniform thickness by using a photo lithography process. During this process, a diffusing angle of the phase mask **120** may be adjusted according to an incident angle of a beam that is shaped and radiated for exposure.

[0042] Referring to FIG. **3**, after light that is spatially distributed at a uniform intensity passes through the phase mask **120**, the light is spatially distributed randomly. In FIG. **3**, a gray scale of a cross-section of a beam corresponds to the various thicknesses of the phase modulation layer **123**. The inventor experimentally ascertained that uniformity of a hologram is improved when recording the hologram by using such light, which will be described below.

[0043] Hereinafter, a detailed configuration of the hologram recording apparatus **100** will be described with reference to FIG. **1**.

[0044] The light source **110** may be a laser light source that outputs a coherent light, and the laser light source may be, for example, a continuous wave (CW) laser or a quasi-CW laser.

[0045] The signal beam optical system **101** is an optical system that divides a beam emitted from the light source **110** into the reference beam R and the signal beam S, modulates the divided signal beam according to hologram pixel information, and directs the modulated signal beam to the hologram recording medium **150**. To this end, the signal beam optical system **101** includes a beam splitting extension portion, the phase mask **120**, a spatial light modulator (SLM) **135**, and an object lens unit **140**.

[0046] The beam splitting extension portion may include a first beam splitter **115** dividing the beam emitted from the light source **110** into the reference beam R and the signal beam S, and a beam extension portion **125** disposed on a light path of the signal beam S.

[0047] The first beam splitter **115** may be, for example, a half mirror. The first beam splitter **115** may transmit about 50% of incident light to use the transmitted incident light as the signal beam S and may reflect about 50% of incident light to use the reflected incident light as the reference beam R. However, the ratio at which the incident light is divided into the signal beam S and the reference beam R is just an example, and the ratio may be differently set. Although FIG. **1** illustrates that light penetrating the first beam splitter **115** is the signal beam S, and light reflected by the first beam splitter **115** is the reference beam R, this is just an example. Alternatively, an optical arrangement of the hologram recording apparatus **100** may be changed so that the light penetrating the first beam splitter **115** is the reference beam R and the light reflected by the first beam splitter **115** is the signal beam S.

[0048] The beam extension portion **125** may enlarge the signal beam S, for example, into a size corresponding to an effective light modulation area of the spatial light modulator **15**, and the beam extension portion **125** may be composed of a plurality of optical elements including at least one lens. The beam extension portion **125** may be composed of a pair of relay lenses as shown in FIG. **2**, but this is not limiting, and the beam extension portion **125** may be composed of different elements, as would be understood by one of skill in the art.

[0049] A filter (not shown) may further be disposed between the light source **110** and the first beam splitter **115**, if desired. For example, a band-pass filter for transmitting only light of a specific wavelength band may further be disposed between the light source **110** and the first beam splitter **115**.

[0050] The SLM **135** modulates the signal beam S based on information regarding an image to be formed in the hologram recording medium **150**, and the SLM **135** may be formed of, for example, a liquid crystal on silicon (LCoS) element.

[0051] The SLM **135** may be a reflective SLM. In this case, a second beam splitter **130** may be disposed between the beam extension portion **125** and the object lens unit **140** as shown in FIG. **1**. The second beam splitter **130** divides light in such a way that light emitted from the beam extension portion **125** is directed to the SLM **135** and light modulated by the SLM **135** is directed to the object lens unit **140**.

[0052] The second beam splitter **130** may be a half mirror that reflects a portion of incident light and transmits the rest of the incident light. Alternatively, the second beam splitter **130** may be a polarizing beam splitter that transmits or reflects light according to a polarization direction of the incident light. In this case, a polarizing plate (not shown) that transmits only light in a specific polarizing direction may further be disposed on a light path of light directed to the second beam splitter **130**. Also, a quarter-wave plate (not shown) may further be disposed between the second beam splitter **130** and the SLM **135**.

[0053] The above description is about a case where the SLM **135** is a reflective SLM. However, this is just an example, and the SLM **135** may be a transmissive SLM. In this case, the second beam splitter **130** is omitted.

[0054] In FIG. **2**, the phase mask **120** is disposed between the first beam splitter **115** and the beam extension portion **125**. However, this is just an example, and the phase mask **120** may be disposed in another location. For example, the phase mask **120** may be disposed between the beam extension portion **125** and the second beam splitter **130** or between the second beam splitter **130** and the object lens unit **140**.

[0055] The object lens unit **140** functions as a Fourier transformation optical system that Fourier transforms the signal beam S modulated by the SLM **135**, that is, the signal beam S including information regarding an image and focuses the signal beam on the hologram recording medium **150**. Although the object lens unit **140** is composed of only one lens in FIG. **1**, this is just an example. Thus, the object lens unit **140** may be composed of two or more lenses, or the object lens unit **140** may include another optical element.

[0056] The reference beam optical system **102** transmits the reference light R divided from the first beam splitter **115** to the hologram recording medium **150**. The reference beam optical system **102** includes an object lens **165** and at least one mirror for adjusting a light path. Although two minors **160** and **170** are shown in FIG. **1**, this is just an example, and thus the reference beam optical system **102** may be modified to various configurations. For example, the minors **160** and **170** may be configured to be rotatable and movable so that the reference beam R is incident on a desired position of the hologram recording medium **150** at a desired incident angle. In particular, the reference beam optical system **102** may be configured in such a way that the reference beam R and the signal beam S are incident on the same position of the hologram recording medium **150**. Also, the reference beam optical system **102** may be configured in such a way that a cross-section of the reference beam R is matched with a cross-section of the signal beam S on the hologram recording medium **150**.

[0057] In the above-described hologram recording apparatus **100**, the signal beam S including information regarding an image encounters the reference beam R in the hologram recording medium **150**, and interference fringes generated when the signal beam S and the reference beam R interfere in each other are recorded in the hologram recording medium **150**.

[0058] FIG. **4** is a diagram showing several positions sampled to measure uniformity, after a white patch is recorded using the hologram recording apparatus **100** of FIG. **1**, according to an embodiment of the present invention.

[0059] There are twenty three sampling positions as shown in Table below. After brightness of the sampling positions is measured, uniformity is analyzed as shown below.

[0060] First, the brightness of the sampling positions is shown in Table below.

97	97	108	95	87
102	106	109	104	90
98	105	111	105	85
	94	104	98	88
	102	105	96	80

[0061] Variables shown in Table below are obtained by Equation, 1−(variable/average_T1), by using a value, i.e., average_T1, obtained by averaging all values shown in Table above.

0.015446	0.015446	0.096205	0.035746	0.116946
0.035305	0.075905	0.106355	0.055605	0.086496
0.005296	0.065755	0.126655	0.065755	0.137246
	0.045896	0.055605	0.005296	0.106796
	0.035305	0.065755	0.025596	0.187996

[0062] Next, percent image uniformity (PIU) is calculated as follows, from an average, i.e., average_T2, of all the variables shown in Table above.

$$PIU=100\times(1-\text{average\_T2})$$

[0063] The PIU obtained through the above-described process is 93%, which is an improved value compared to the uniformity of a hologram recorded in a general hologram recording apparatus that does not use the phase mask **120** of the present exemplary embodiment. Also, a fill factor of a hologram pixel is analyzed as 90%, which is an improved value compared to the uniformity, i.e., 40%, of a hologram recorded in a general hologram recording apparatus.

[0064] FIG. **5** is a schematic view of a hologram recording apparatus **200** according to another exemplary embodiment.

[0065] The hologram recording apparatus **200** includes the light source **110**, a signal beam optical system **201** that divides a beam emitted from the light source **110** into a reference beam R and a signal beam S, modulates the divided signal beam according to hologram pixel information, and radiates the modulated signal beam onto the hologram recording medium **150**, and a reference beam optical system **202** that radiates the reference beam onto the hologram recording medium **150**.

[0066] Comparing the hologram recording apparatus **100** of FIG. **1** and the hologram recording apparatus **200** of the current embodiment, the hologram recording apparatus **200** further includes a light guide member **226** for guiding light between the light source **110** and the hologram recording medium **150** by total reflection. Also, the hologram recording apparatus **200** of the current embodiment has a structure modified from that of FIG. **1** in such a way that the beam splitting extension portion, the second beam splitter **130**, and the object lens unit **140** of FIG. **1** is modified to a first holographic optical element (HOE) **223**, a second HOE **232**, and a third HOE **234**, respectively.

[0067] The HOE is a kind of diffractive optical element that has a structure with a minute grating pattern and is manufactured using a holographic technology. The HOE may complexly perform various optical functions according to the structure of the grating pattern.

[0068] The light guide member **226** may be formed of a transparent plastic material or a glass material and may guide incident light by total internal reflection.

[0069] The hologram recording apparatus **200** may be made more compact by disposing the HOE with appropriate functions on the light guide member **226**.

[0070] The first HOE **223** performs a beam splitting function and a beam extending function and may be disposed on the light guide member **234**. If light emitted from the light source **110** is incident on the first HOE **223**, the light is diffracted at a predetermined angle and is divided into the signal beam S traveling inside the light guide member **226** and the reference beam R which is transmitted through the first HOE **223**. Although FIG. **4** illustrates that a beam emitted from the light source **110** is vertically incident on the first HOE **223**, the present invention is not limited thereto, and thus the beam may be obliquely incident on the first HOE **223** at a predetermined angle.

[0071] The second HOE **232** collimates the signal beam S, which is guided inside the light guide member **226** and has been incident on the second HOE **232**, and allows the signal beam S to be incident on the SLM **235**. The second HOE **232** includes a minute grating pattern appropriate for the above-described functions of the second HOE **232**. The second HOE **232** may be disposed on the light guide member **234** to face the SLM **235**.

[0072] A minute grating pattern is formed in the third HOE **234** to perform a function of a Fourier objective lens. The signal beam S, which has been modulated by the SLM **235** and has passed through the light guide member **226**, is incident on the third HOE **234** and is transmitted therethrough to a desired position on the hologram recording medium **150**. The third HOE **234** may be disposed on the light guide member **226**, opposite the hologram recording medium **150**.

[0073] The phase mask **120** shown in FIG. **1** may be integrally formed with any one of the first, second, and third HOEs **223**, **232**, and **234** in the current embodiment. For example, the any one of the first, second, and third HOEs **223**, **232**, and **234** may be configured in such a way that a diffraction pattern appropriate for a function to be performed is formed in the phase mask **120** having the above-described structure.

[0074] The reference beam optical system **202** transfers the reference beam R divided from the first HOE **223** to the hologram recording medium **150** and includes the object lens **165** and at least one minor for adjusting a light path. Although FIG. **5** illustrates that the reference beam optical system **202** have the same configuration as the reference beam optical system **102** shown in FIG. **1**, this is just an example. Thus, the reference beam optical system **202** may be modified to have a structure using a light guide member and an HOE, similar to the signal beam optical system **201**.

[0075] The above-described phase mask improves uniformity of an optical system for recording a hologram and improves a fill factor of a hogel.

[0076] Accordingly, the hologram recording apparatus using the above-described phase mask has an improved uniformity between pixels and may record a hologram that is insensitive to an angular selectivity.

[0077] It should be understood that the exemplary embodiments described herein should be considered in a descriptive sense only and not for purposes of limitation. Descriptions of features or aspects within each embodiment should typically be considered as available for other similar features or aspects in other embodiments.

What is claimed is:

1. A phase mask comprising:

a phase modulation layer that modulates a phase of incident light, such that the phase modulation layer imparts an optical phase delay to the incident light based on a location of the phase modulation layer on which the incident light is incident, wherein the optical phase delay is in a range between 0 and 2π.

2. The phase mask of claim **1**, wherein the phase modulation layer comprises a transparent material with a non-uniform thickness having a value between 0 and $n\lambda$, wherein n is a refractive index of the transparent material and λ is denotes a wavelength of the incident light.

3. The phase mask of claim **2**, wherein the non-uniform thickness of the transparent material varies among N different thicknesses, wherein N is a natural number.

4. The phase mask of claim **1**, wherein a cross-section of light transmitted by the phase mask has a quadrilateral shape.

5. The phase mask of claim **2**, wherein the phase modulation layer comprises a photoresist.

6. The phase mask of claim **2**, wherein a thickness of the phase modulation layer is non-uniform, and the phase modulation layer is formed using a photolithography process in which a diffusing angle is determined according to an incident angle of a beam that is shaped for exposure.

7. The phase mask of claim **1**, further comprising a glass substrate that supports the phase modulation layer.

8. A hologram recording apparatus comprising:
a light source;
a signal beam optical system comprising:
a beam splitter that divides a beam emitted from the light source into a reference beam and a signal beam,
a spatial light modulator that modulates the signal beam according to hologram pixel information, and radiates the modulated signal beam onto a hologram recording medium, and
a phase modulation layer that modulates a phase of the signal beam, such that the phase modulation layer imparts an optical phase delay to the signal beam based on a location of the phase modulation layer on which the signal beam is incident,
wherein the optical phase delay is in a range between 0 and 2π; and
a reference beam optical system that radiates the reference beam onto the hologram recording medium.

9. The hologram recording apparatus of claim **8**, wherein the signal beam optical system further comprises:
a beam extension portion that extends a diameter of the signal beam; and
an object lens unit that focuses the modulated signal beam modulated by the spatial light modulator on the hologram recording medium.

10. The hologram recording apparatus of claim **9**, wherein the beam extension portion comprises:
a pair of relay lenses disposed on a light path of the signal beam.

11. The hologram recording apparatus of claim **9**, wherein the spatial light modulator is a reflective spatial light modulator.

12. The hologram recording apparatus of claim **11**, wherein the beam splitter is a first beam splitter and the hologram apparatus further comprises a second beam splitter disposed between the beam extension portion and the object lens unit, wherein the second beam splitter divides light incident thereon such that light emitted from the beam extension portion is directed to the spatial light modulator and light modulated by the spatial light modulator is directed to the object lens unit.

13. The hologram recording apparatus of claim **12**, wherein the beam splitting extension portion, the second beam splitter, and the object lens unit comprise a first holographic optical element, a second holographic optical element, and a third holographic optical element, respectively.

14. The hologram recording apparatus of claim **13**, wherein the phase mask is integrally formed with one of the first holographic optical element, the second holographic optical element, and the third holographic optical element.

15. The hologram recording apparatus of claim **14**, wherein one of the first holographic optical element, the second holographic optical element, and the third holographic optical element comprises a diffraction grating pattern formed in the phase mask.

16. The hologram recording apparatus of claim **13**, wherein the phase mask is disposed adjacent to one of the first holographic optical element, the second holographic optical element, and the third holographic optical element.

17. The hologram recording apparatus of claim **13**, further comprising a light guide member, which guides light by total internal reflection, disposed between the light source and the hologram recording medium.

18. The hologram recording apparatus of claim **17**, wherein the first holographic optical element, the second holographic optical element, and the third holographic optical element are disposed on the light guide member.

19. The hologram recording apparatus of claim **8**, wherein the reference beam optical system comprises an object lens for focusing the reference beam on the hologram recording medium, and at least one minor for adjusting a light path.

20. A hologram recording apparatus comprising:
a light source;
a beam splitter which divides light from the light source into a reference beam and a signal beam;
a phase modulation layer which modulates a phase of the signal beam such that a different optical phase delay is imparted to each of a plurality of portions of the signal beam, wherein the optical phase delay is in a range between 0 and 2π;
a spatial light modulator which modulates the signal beam according to hologram pixel information.

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