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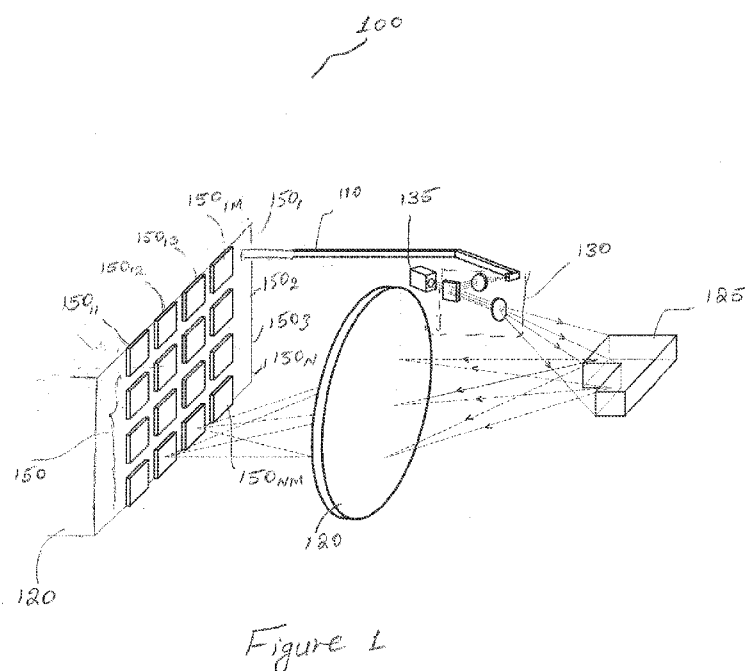
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(54) **Title:** COHERENT CAMERA



(57) **Abstract:** A camera includes, in part, an optical signal source generating a frequency varying optical signal, a multitude of pixels arranged along rows and columns, an optical focusing element, and an opto-electronic circuit. A portion of the optical signal generated by the optical signal is caused to reflect from a target object and then directed toward the pixels. A multitude of samples of a second portion of the optical signal are combined with the signals received by the pixels to generate a multitude of combined optical signals. The optical signals so combined are converted to electrical signals. Each electrical signal has a frequency defined by a difference between a frequency of the second portion of the optical signal and a frequency of a signal received from a pixel. The frequency differences are used to form an image of the target object.

COHERENT CAMERA

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CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] The present application claims benefit under 35 USC 119 (e) of U.S. provisional application No. 61/700,722, filed September 13, 2012, entitled "Coherent Camera", the content of which is incorporated herein by reference in its entirety.

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BACKGROUND OF THE INVENTION

[0002] A number of conventional techniques exist to capture a 3D image of an object. In accordance with one such technique, to form a 3D picture of an object, two or more images of the object are captured from slightly different vantage points or angles. The pictures, which may be taken using two distinct lenses to form two separate images on two image sensors, or on different areas of a photograph film, provide the spatial displacement and depth necessary to recreate the three dimensional visual effect.

BRIEF SUMMARY OF THE INVENTION

[0003] A camera in accordance with one embodiment of the present invention includes, in part, an optical signal source generating a time varying optical signal, a multitude of pixels arranged along N rows and M columns where M and N are integer numbers, an optical focusing element adapted to focus a reflected signal toward the pixels to enable the pixels receive the reflected signal, and an opto-electronic circuit adapted to combine a second portion of the optical signal with the signals received by at least a subset of the pixels to generate data representative of an image of the target object. The reflected signal is generated by causing a reflection of a first portion of the optical signal from the target object.

[0004] In accordance with one embodiment the camera further includes, an optical system adapted to direct the first portion of the optical signal toward the target object. In one embodiment the optical signal source is a laser. In one embodiment, the opto-electronic circuit includes, in part, a multitude of splitters adapted to generate a multitude of samples of the second portion of the optical signal, and a multitude of combiners each adapted to combine a

sample of the second portion of the optical signal with a signal received from a different one of the pixels to generate a multitude of combined optical signals.

[0005] In one embodiment, the camera further includes, in part, a multitude of opto-electronic components each associated with a different one of the combiners and a different one of the pixels and adapted to convert the combined optical signal it receives from its associated combiner to an electrical signal. In one embodiment, each opto-electronic component is a photo-diode adapted to generate a current signal whose frequency is defined by a difference between a frequency of the second portion of the optical signal and a frequency of the signal the photo-diode receives from its associated pixel.

[0006] In one embodiment, the camera further includes, in part, a signal processing system adapted to determine data representative of the image of the target object by comparing the frequencies of the current signals generated by the photodiodes. In one embodiment, each photodiodes is adapted to filter out high frequency components of the signals it receives. In one embodiment, the camera further includes, in part, an optical path adapted to deliver the second portion of the optical signal to the optical system.

[0007] In one embodiment, the pixels, splitters, combiners, opto-electronic components and the signal processing system are formed on a semiconductor substrate. In one embodiment, the optical signal source is also formed on the semiconductor substrate. In one embodiment, the image captured by the camera is a 3-D image. In one embodiment, the optical signal generated by the optical signal source has a variable frequency.

[0008] A method of forming an image of a target object, in accordance with one embodiment of the present invention, includes, in part, generating a time varying optical signal, directing a first portion of the optical signal toward the target object to generate a reflected optical signal, focusing the reflected optical signal onto a multitude of pixels positioned along rows and columns to enable the pixels receive the reflected optical signal, and combining a second portion of the optical signal with the signals received by at least a subset of the pixels thereby to generate data representative of the image of the target object.

[0009] In one embodiment, the method further includes, in part, generating the time varying optical signal using a laser. In one embodiment, the method further includes, in part, generating a multitude of samples of the second portion of the optical signal, and combining each sample of the second portion of the signal with a different one of signals received by the

pixels thereby to generate a multitude of combined optical signals. In one embodiment, the method further includes, in part, converting the combined optical signals to electrical signals.

[0010] In one embodiment, the frequency of each electrical signal is defined by a difference between a frequency of the second portion of the optical signal and a frequency of the signal received from an associated pixel. In one embodiment, the method further includes, in part, comparing the plurality of frequencies of the electrical signals to form the data representative of the image of the target object.

[0011] In one embodiment, the method further includes, in part, filtering out high frequency components of the electrical signals. In one embodiment, the method further includes, in part, delivering the first portion of the optical signal toward the target object via an optical system. In one embodiment, the method further includes, in part, generating the optical signal using an optical source formed on a semiconductor substrate, and forming the on the semiconductor substrate. In one embodiment, the pixels are formed on a semiconductor substrate using a silicon-on-insulator process.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] Figure 1 is a simplified schematic diagram of a coherent camera, in accordance with one embodiment of the present invention.

[0013] Figure 2 is a simplified view of a multitude of components and signal paths disposed in the coherent camera of Figure 1, in accordance with one embodiment of the present invention.

[0014] Figure 3 is an exemplary equivalent circuit diagram of the components and signal paths shown in Figure 2.

[0015] Figure 4 is a schematic view of a number of components of coherent camera, in accordance with one exemplary embodiment of the present invention.

[0016] Figure 5 shows the coherent camera of Figure 1 positioned to form a phase contrast view of an object having different dielectric constants, in accordance with one exemplary embodiment of the present invention.

[0017] Figure 6 is a perspective view of one of the pixels disposed in the coherent camera of Figure 1, in accordance with one exemplary embodiment of the present invention.

[0018] Figure 7 is a simplified block diagram of a signal processing system used in a coherent camera, in accordance with one embodiment of the present invention.

[0019] Figure 8 shows the phases of a number of current waveforms relative to that of a reference signal as detected by the signal processing system, in accordance with one

5 exemplary embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0020] A coherent camera, in accordance with one embodiment of the present invention, captures data representative of both amplitude and phase of optical signals emitted from the object being viewed. Since both the amplitude and phase are captured, electronically controlled fast segment-selective zooming may be performed in creating different image sizes associated with objects positioned at different distances. The coherent camera may be used in numerous applications, such as mono-static and bi-static radars, phased array receivers, range and velocity sensors, Doppler shift detection systems, scanning systems, games, optical communication systems, electronically controlled ultra-fast focus, phased array based detection, object tracking, velocity detection, ranging, phase contrast imaging, and the like.

[0021] Figure 1 is a simplified schematic diagram of a coherent camera 100, in accordance with one embodiment of the present invention. Coherent camera 100 is shown as including, in part, an array of pixels 150, a coherent signal source 135, an optical system 130, and an optical focusing element 120. The optical focusing element 120 may be a lens and is referred to as such hereinafter. Pixel array 150 is formed on, for example, a semiconductor substrate 120, and includes $N \times M$ array of pixels arranged along N rows and M columns. For example, row 1 is shown as including pixels 150_{11} , $150_{12} \dots 150_{1M}$. In the following description, pixel 150_{ij} is understood to refer to a pixel disposed in row i and column j of array 150. Coherent camera 100 also includes a multitude of Y-junctions, combiner arrays, photodiodes, and a control/processing circuitry formed in substrate 220, as shown in detail in Figures 2 and 3.

[0022] Signal source 135, which may be a laser, generates a coherent signal. The frequency of the signal generated by signal source 135 is chirped so as to increase or decrease with time, either linearly or non-linearly. The signal generated by light source 135 is split into at least two parts by optical system 130. A first portion of the light so split is directed toward target object 125 via optical system 130, reflects off the various surfaces of object 125 and is focused by lens 120 toward pixel array 150. A second portion of the light so split, hereinafter

referred to as the reference signal, is directed towards coherent camera 100 via optical path 110. As is described further below, the amplitudes associated with the image of the target object being formed is captured by the intensity of the reflected signal and the depth of the image being formed in each pixel is captured by correlating the reference signal with the signal received by that pixel, as described further below.

[0023] Signals that are reflected from different points of target object 125 with different depths experience different time delays as they arrive and get captured by the pixels.

Therefore, as the frequency of light source 135 is chirped, signals received by the pixels from different points of object 125 with different depths, will have different optical frequencies.

By correlating the signal received at each pixel with the reference signal, different electrical frequencies associated with different pixels are detected. The frequencies so detected provide information about the positions and depths of various points of target object 125 relative to the camera, thereby providing a 3D image of the object.

[0024] Figure 2 is a simplified view of a multitude of components and signal paths formed in substrate 120 and disposed in coherent camera 100 (not shown in Figure 1). Only the paths associated with four of the pixels, namely pixels 150₁₁, 150₁₂, 150₁₃, and 150₁₄ are shown.

Although not shown, it is understood that substrate 120 includes similar paths, optical combiners, and photodiodes associated with each pixels 150_{ij}, where i is an index ranging from 1 to N, and j is an index ranging from 1 to M. Each pixel in array 150 includes a grating coupler having a multitude of grooves. When an optical signal strikes the camera lens, it is caused to pass through the gratings and subsequently combine with the various samples of reference signal in the combiners. For example, the optical signal received by pixel 150₁₁ is directed to combiner 40 via optical signal path 32. Combiner 40 receives a portion of the reference signal via paths 10 and 12. Likewise, combiner 44 is adapted to combine the optical signal it receives from pixel 150₁₃—via optical signal path 36—with a sample of the reference signal the combiner receives via paths 20 and 22. Therefore, each combiner is adapted to combine a sample of the reference signal with an optical signal received from the combiner's associated pixel.

[0025] As described above, each combiner combines the signal it receives from its associated pixel with a sample of the reference signal to generate a combined signal that in one embodiment is representative of the sum of these two signals. For example, assume that the signal received by combiner 40 from pixel 150₁₁ is represented by A, and the sample of

reference signal received by combiner 40 is represented by B. Optical signals A and B travel in two different paths and thus experience different time delays. Hence, since the light source 135 is frequency chirped, signals A and B will have different frequencies at the input of the combiner 40. The optical signal representative of the sum of these two optical signals (A+B) is applied to a photodiode. For example, photodiode 50 is shown as receiving the optical output signal (A+B) of combiner 40; and photodiode 52 is shown as receiving the optical output signal of combiner 42. Each photodiode is adapted to generate a signal representative of nearly the square of the signal it receives. For example, in response to the received signal (A+B), photodiode 50 generates a signal defined by $(A+B)^2$, which is equivalent to: $A^2 + B^2 + 2AB$

[0026] Since signals A and B are optical signals, signals A^2 and B^2 have relatively very high frequencies that are outside the frequency response range of the photodiodes and are thus filtered out. The product AB represents a mixing of signals A and B. The Fourier transform of the product of two time-domain sinusoidal signals A and B, has two frequencies positioned at frequencies A+B and A-B. The frequency of the signal component defined by A+B is relatively high and outside the frequency response range of the photodiodes and is thus filtered out.

[0027] The remaining frequency component of the photodiode current, namely A-B which represents the difference between the frequency of the reference signal and the received signal, is within the frequency response range of the photodiode. Accordingly, the frequency, phase, and amplitude of the photodiode current associated with each pixel is used to represents the distance from the camera of a region of the object reflecting the optical signal that is captured by that pixel. In one embodiment, the camera can achieve 100 μm depth or spatial resolution by processing the frequency and phase of the photodiode current. Currents I_1, I_2, I_3, I_4 generated respectively by photodiodes 50, 52, 54, and 56 are applied to a control and signal processing system 200 adapted to implement an algorithm for determining the relative position of an image captured by each pixel relative to the positions of the remaining images captured by the other pixels. Although Figure 2 is shown as having four pixel and four associated photodiodes for simplicity, it is understood that coherent camera 100 of Figure 1, has $i \times j$ pixels each having an associated photodiode (i.e., $i \times j$ photodiodes), where i and j may be any integers.

[0028] Figure 3 is an exemplary equivalent circuit diagram of the components and signal paths shown in Figure 2. Combiners 40, 42, 44, 46 together with photodiodes 50, 52, 54, 56 of Figure 2 are equivalently represented as mixers 60, 62, 64, 66, and low-pass filters 70, 72, 74, 76. Each mixer performs a mixing operation to provide, for example, the product of a sample of a reference signal and a received signal. The low-pass filters perform the filtering operations that filter out the high frequency components of the signal generated by the photodiodes. For example, as described above, the low-pass filters filter out the high frequency components associated with signals A^2 , B^2 , and $A+B$, while passing the frequency component associated with signal $A-B$.

[0029] As was described above, control and signal processing system 200 is adapted to execute an algorithm designed to determine the relative positions of various points of a target object as captured by the pixels. To achieve this, control and signal processing system 200 may perform any one of a number of linear or non-linear transformations. Figure 7 is a simplified block diagram of a signal processing system 200, in accordance with one embodiment of the present invention. Although the signal processing system of Figure 7 is shown as having only four signal processing paths processing the currents signals associated with only four photodiodes, namely I_1 , I_2 , I_3 and I_4 (see also Figure 2) it is understood that a signal processing system disposed in a coherent camera in accordance with the present invention may have $i \times j$ signal processing paths, with i and j representing the number of pixels disposed along the rows and columns of the pixel array, as described above.

[0030] In the embodiment shown in Figure 7, the coarse spatial position of the various points of the target object is determined by detecting the frequency of one of the currents (e.g. I_4) using a frequency counter 310. Fine spatial resolution of the various point of the target object is determined by comparing the phase of each current waveform to the time-varying electrical reference signal S_{ref} using digital signal processing unit 340. The phase of each such current waveform relative to that of the reference signal S_{ref} is detected using zero-crossing detector blocks 312, 314, 316, 318, 330. Figure 8 shows exemplary waveforms of the reference signal S_{ref} and current waveforms I_1 , I_2 , I_3 and I_4 . As is seen from Figure 8, current waveforms I_1 , I_2 , I_3 and I_4 are shown as having detected phases of x_1 , x_2 , x_3 and x_4 relative to reference signal S_{ref} .

[0031] In accordance with another embodiment, the zero-crossing detectors disposed in control and signal processing system 200 are used to find the frequency of the current

waveform associated with each photodiode. In accordance with yet another embodiment of the control and signal processing system 200, the photodiode current waveforms are digitized and supplied to a Fourier transform block configured to determine the frequency of the current generated by each photodiode.

5 [0032] In accordance with one linear transformation, the algorithm sets the frequency of the photodiode associated with one of the pixels, e.g. pixel 15₁₁ as the reference frequency. The algorithm then subtracts the frequency associated with the remaining $(i \times j - 1)$ pixels from the reference frequency to determine the distance by which the images captured by the remaining $(i \times j - 1)$ pixels are, for example, ahead or behind the image captured by the
10 reference pixel, thereby to form a 3D image of the target object. It is understood that control and signal processing system 200 may use any other linear or non-linear transformation algorithm to make such determinations by using the frequency of the currents generated by the photodiodes.

[0033] Figure 4 is a schematic view of a number of components of coherent camera 300
15 formed in a semiconductor substrate 500, using for example a silicon-on-insulator process, in accordance with one exemplary embodiment of the present invention. Coherent camera 300 is shown as including a 4x4 array of pixels for simplicity. It is understood, however, that coherent camera 200 may include an NxM array of pixels, where N and M are any positive integers. Coherent camera 200 is also shown as including, in part, an input source 205
20 generating reference signal 125, signal splitters 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, 40, 42, 44, 46, 48, combiners 80_k, wherein k is an integer ranging from 1 to 16 in this exemplary embodiment, and photodiodes 90_k. In one embodiment, each splitter may be a Y-junction, and input signal source 135 may be a laser that may or may not be integrated on substrate 500. Coherent camera 300 also includes a number of optical signal channels that deliver the
25 optical signals received by the pixels as well as the different samples of the reference signal to the combiners, as described further below.

[0034] The reference signal 125 generated by input source 205 is split multiple times to generate multiple samples which are delivered to combiners 80_k. For example, reference signal 125 after being split by splitters 20, 22, 26, 34 is delivered to optical signal combiners
30 80₁ and 80₂. Likewise, the samples of the reference signal 125 that are delivered to combiners 80₉ and 80₁₀ are generated by splitters 20, 24, 30, and 42. Each combiner is also adapted to receive a signal from an associated pixel. For example, in the embodiment shown in Figure 4,

combiner 80₁ receives the signal from its associated pixel 210₁₄ via optical channel 85₁; and combiner 810₁₆ receives the signal from its associated pixel 210₄₁.

[0035] Each combiner is adapted to combine the signal it receives from its associated pixel with a sample of the reference signal to generate and deliver the combined signal to an associated photodiode. For example, combiner 80₁ combines the signal it receives from associated pixel 210₁₄ with the sample of the reference signal it receives from coupler 34 to generate a combined signal that it delivers to photodiode 90₁. Likewise, for example, combiner 80₄ combines the signal it receives from associated pixel 210₄₄ with the sample of the reference signal it receives from coupler 36 to generate a combined signal that it delivers to photodiode 90₄.

[0036] As was described above, in one embodiment, the combined signal generated by each combiner is the sum of the two signals that the combiner receives. The signal generated by each combiner 80_k is delivered to an associated photodiode 90_k. In response, each photodiode 90_k generates a current whose frequency is defined by the difference between the frequencies of the signals that the photodiode's associated combiner receives, as described above in connection with Fig. 2.

[0037] Coherent camera 300 also includes a control and signal processing system (not shown in Figure 4) adapted to form a 3D image of a target object by determining the relative positions of an image captured on each pixel using the frequency of the currents generated by the pixel's associated photodiode. To achieve this, as was described above in reference to Figure 2, the control and signal processing executes an algorithm to determine the relative positions of various points of an object as captured by the pixels. For example, in accordance with one linear transformation, the algorithm sets the current frequency of the photodiode associated with pixel 210₁₁ as the reference frequency. The algorithm, knowing the distances between various pixels, subtracts the frequency of the photodiode currents associated with the remaining pixels from the reference frequency to determine the distance by which the images captured by the remaining pixels are, for example, either behind or ahead of the image of the reference pixel, thereby to form a 3D image of the target object. It is understood that the control and signal processing system may use any other linear or non-linear algorithm to determine the relative positions of the images captured by the pixels by using the frequency of the currents generated by their associated photodiodes.

[0038] Figure 5 shows coherent camera 100 positioned to capture a view of object 140 that includes a first portion 142 having a dielectric constant of ϵ_1 , and a second portion 144 having a dielectric constant of ϵ_2 . Since the phase and amplitude of the signal received by each pixel is indicative of the dielectric constant of the object from which the signal is reflected off of, coherent camera 100, in accordance with embodiments of the present invention, is also adapted to form an image by comparing and contrasting the phases of the received signals. In other words, because the dielectric constants of regions 142 and 144 are different, the phases/frequency of the signals received by the pixels from regions 142 and 144 are also different. The phase differences so detected by coherent camera 100 are used by control and signal processing 200 to form a phase contrast view of object 140. Consequently, a coherent camera 100, in accordance with embodiments of the present invention, is adapted to detect both frequency shifts as well as phase shifts to form a phase contrast views of the objects.

[0039] Figures 6 is a perspective view of an exemplary embodiment of the pixels used in pixel array 150 of coherent camera 100 of Figure 1. The pixel shown in Figure 6 is an optical grating shown as including four similarly sized grooves 30₁, 30₂, 30₃ and 30₄. Although the exemplary optical grating is shown as including four grooves, it is understood that the optical grating may have more or fewer than four grooves.

[0040] The above embodiments of the present invention are illustrative and not limitative. Embodiments of the present invention are not limited by the number of pixels in the pixel array, the wavelength of the optical source that generates a reference signal, the type of frequency transformation, the type of optical signal splitter, combiner, optical waveguide, and the like. Embodiments of the present invention are not limited by the number or shape of grooves in each pixel, nor are they limited by the type of optical-to-electrical signal converter, photodiode or otherwise, used to convert the optical signal to an electrical signal. Embodiments of the present invention are not limited by the type of substrate, semiconductor or otherwise, in which various optical and electrical components of the camera are formed. Other additions, subtractions or modifications are obvious in view of the present disclosure and are intended to fall within the scope of the appended claims.

WHAT IS CLAIMED IS:

1 1. A camera comprising:
2 an optical signal source generating an signal;
3 a plurality of pixels arranged along N rows and M columns, where M and N
4 are integer numbers;
5 an optical focusing element adapted to focus a reflected signal toward the
6 plurality of pixels thereby enabling the plurality of pixels to receive the reflected signal, said
7 reflected signal being generated by causing a reflection of a first portion of the optical signal
8 from the target object; and
9 an opto-electronic circuit adapted to combine a second portion of the optical
10 signal with the signals received by at least a subset of the plurality of pixels to generate data
11 representative of an image of the target object.

1 2. The camera of claim 1 further comprising:
2 an optical system adapted to direct the first portion of the optical signal toward
3 the target object.

1 3. The camera of claim 1 wherein said optical signal source is a laser.

1 4. The camera of claim 1 wherein said opto-electronic circuit comprises:
2 a plurality of splitters adapted to generate a plurality of samples of the second
3 portion of the optical signal; and
4 a plurality of combiners each adapted to combine a sample of the second
5 portion of the optical signal with a signal received from a different one of the plurality of
6 pixels, thereby to generate a plurality of combined optical signals.

1 5. The camera of claim 4 further comprising:
2 a plurality of opto-electronic components each associated with a different one
3 of the combiners and a different one of the pixels and adapted to convert the combined
4 optical signal it receives from its associated combiner to an electrical signal.

1 6. The camera of claim 5 wherein each opto-electronic component is a
2 photo-diode adapted to generate a current signal whose frequency is defined by a difference
3 between a frequency of the second portion of the optical signal and a frequency of the signal
4 the photo-diode receives from its associated pixel.

1 7. The camera of claim 5 wherein said camera further comprises a signal
2 processing system adapted to determine data representative of the image of the target object
3 by comparing the plurality of frequencies of the current signals generated by the plurality of
4 photodiodes.

1 8. The camera of claim 7 wherein each of the photodiodes is adapted to
2 filter out high frequency components of the signals it receives.

1 9. The camera of claim 1 further comprising:
2 an optical path adapted to deliver the second portion of the optical signal to the
3 optical system.

1 10. The camera of claim of 7 wherein the plurality of pixels, the plurality
2 of splitters, the plurality of combiners, the plurality of opto-electronic components and the
3 signal processing system are formed on a semiconductor substrate.

1 11. The camera of claim of 10 wherein said optical signal source is formed
2 on the semiconductor substrate.

1 12. The camera of claim 1 wherein said image is a 3-D image.

1 13. The camera of claim 1 wherein the optical signal generated by the
2 optical signal source has a variable frequency.

1 14. A method of forming an image of a target object, the method
2 comprising:

3 generating an optical signal;

4 directing a first portion of the optical signal toward the target object to
5 generate a reflected optical signal;

6 focusing the reflected optical signal onto a plurality of pixels arranged along
7 rows and columns thereby enabling the plurality of pixels to receive the reflected optical
8 signal; and

9 combining a second portion of the optical signal with the signals received by
10 at least a subset of the plurality of pixels thereby to generate data representative of the image
11 of the target object.

1 15. The method of claim 14 further comprising:
2 generating the optical signal using a laser.

1 16. The method of claim 14 further comprising:
2 generating a plurality of samples of the second portion of the optical signal;

3 and

1 combining each sample of the second portion of the signal with a different one
2 of the plurality of signals received by the pixels thereby to generate a plurality of combined
3 optical signals.

1 17. The method of claim 16 further comprising:
1 converting the plurality of combined optical signals to a plurality of electrical
2 signals.

1 18. The method of claim 17 wherein a frequency of each one of the
2 plurality of electrical signals is defined by a difference between a frequency of the second
3 portion of the optical signal and a frequency of the signal received from a different one of the
4 plurality pixels.

1 19. The method of claim 17 further comprising:
2 comparing the plurality of frequencies of the electrical signals to form the data
3 representative of the image of the target object.

1 20. The method of claim 19 further comprising:
1 filtering out high frequency components of the electrical signals.

1 21. The method of claim 14 further comprising:
1 delivering the first portion of the optical signal toward the target object via an
2 optical system.

1 22. The method of claim 19 further comprising:
2 generating the optical signal using an optical source formed on a
3 semiconductor substrate; and
4 forming the plurality of pixels on the semiconductor substrate.

1 23. The method of claim 19 wherein the plurality of pixels are formed on a
2 semiconductor substrate using a silicon-on-insulator process.

1 24. The method of claim 14 wherein the optical signal has a variable
2 frequency.

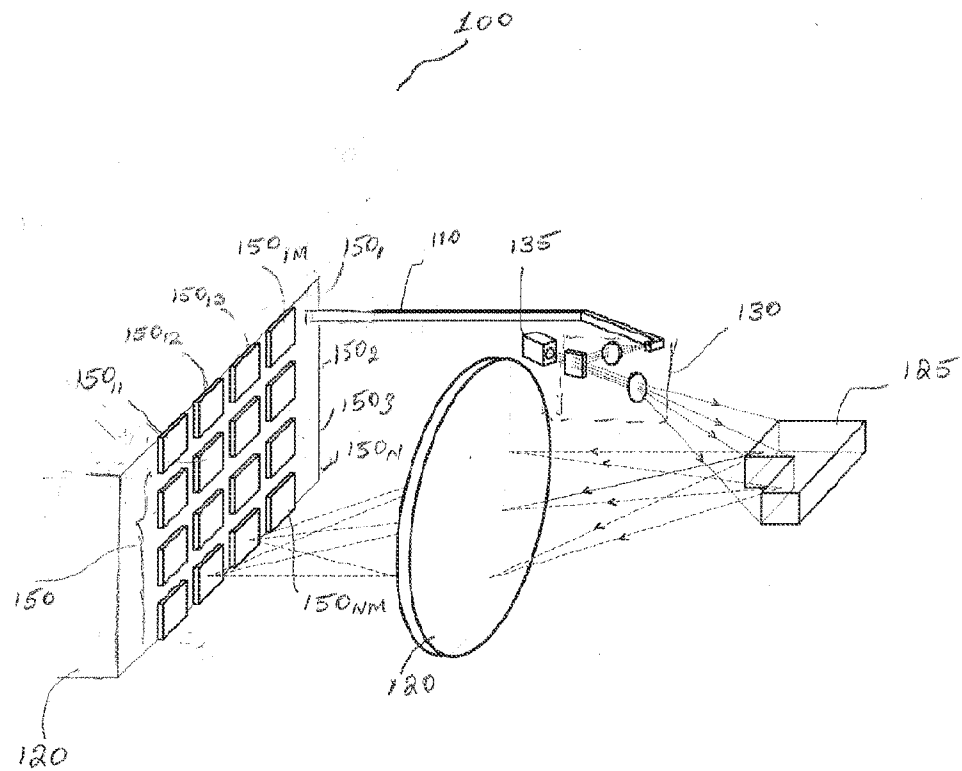


Figure 1

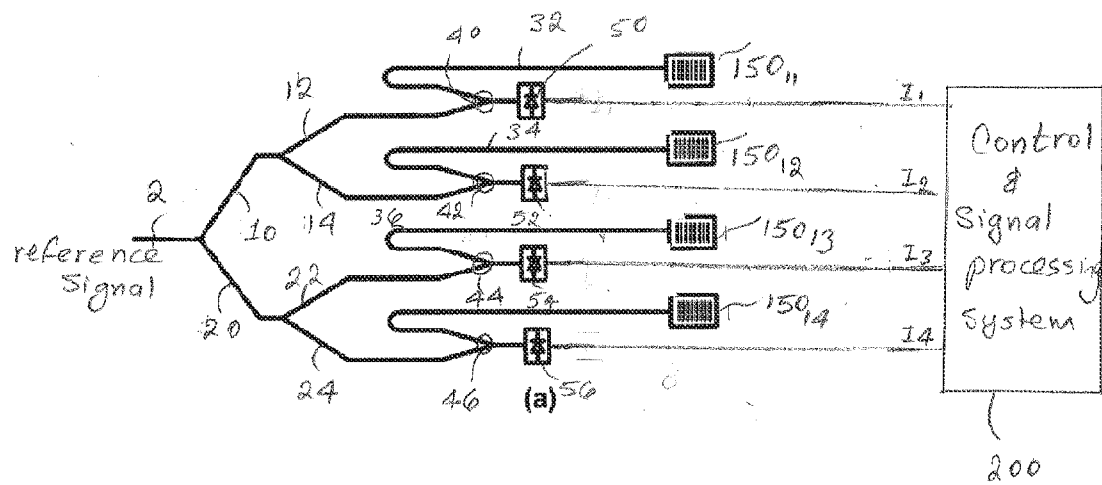


Figure 2

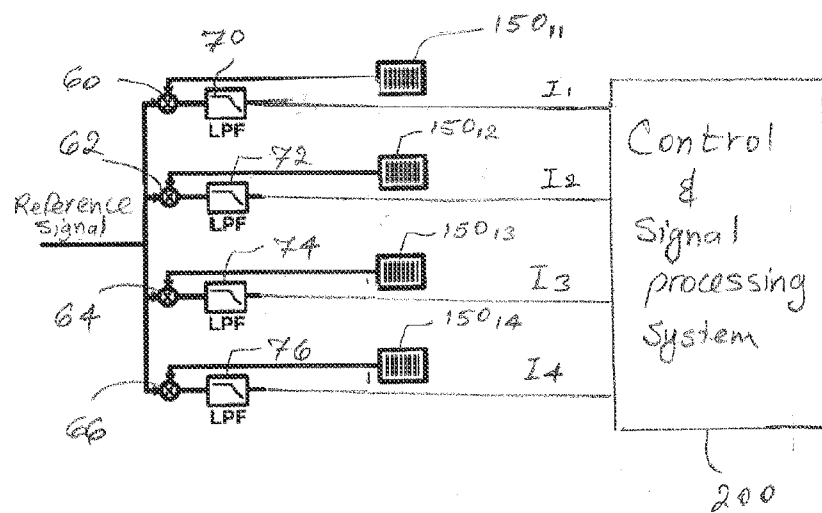


Figure 3

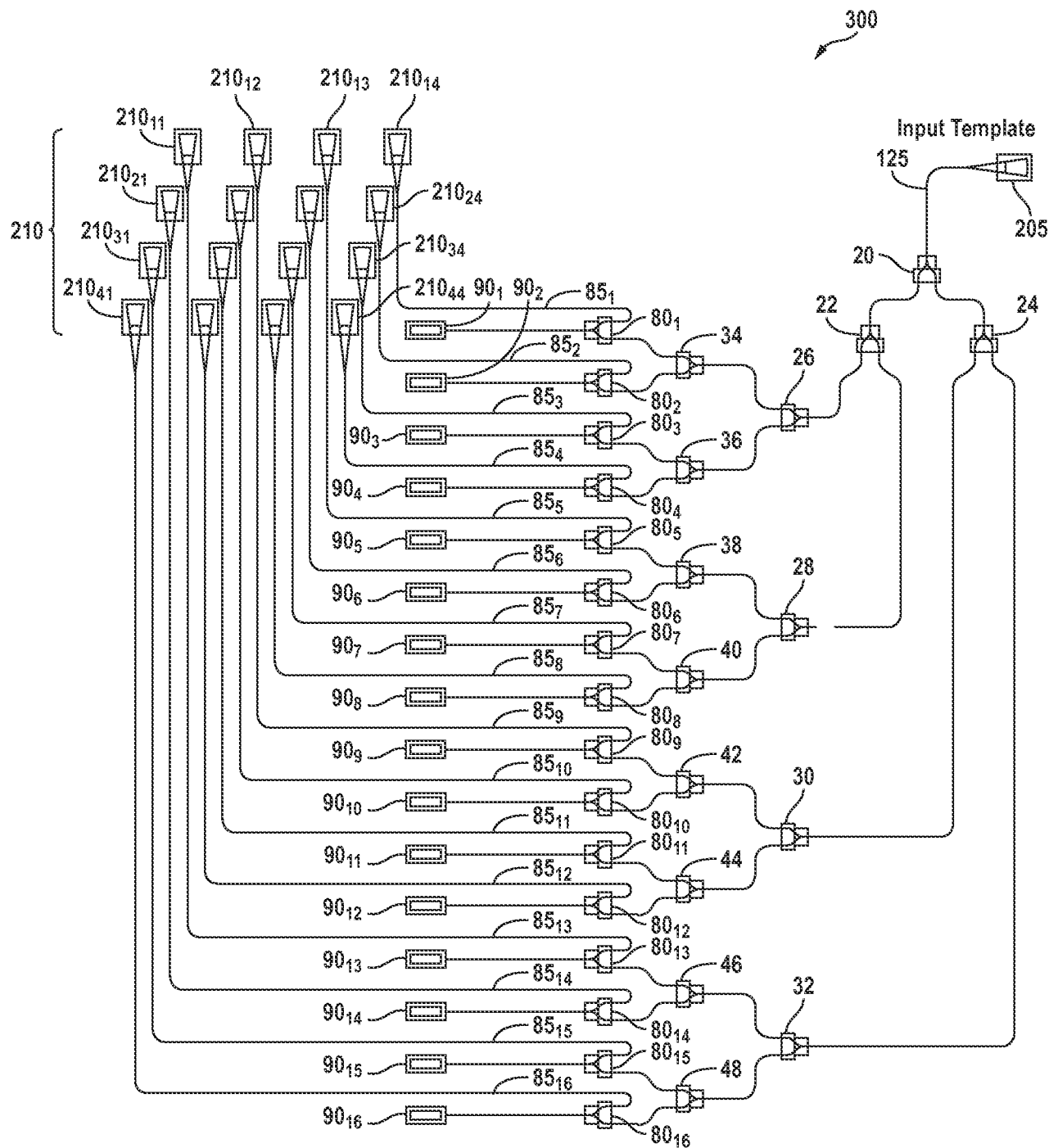


FIG. 4

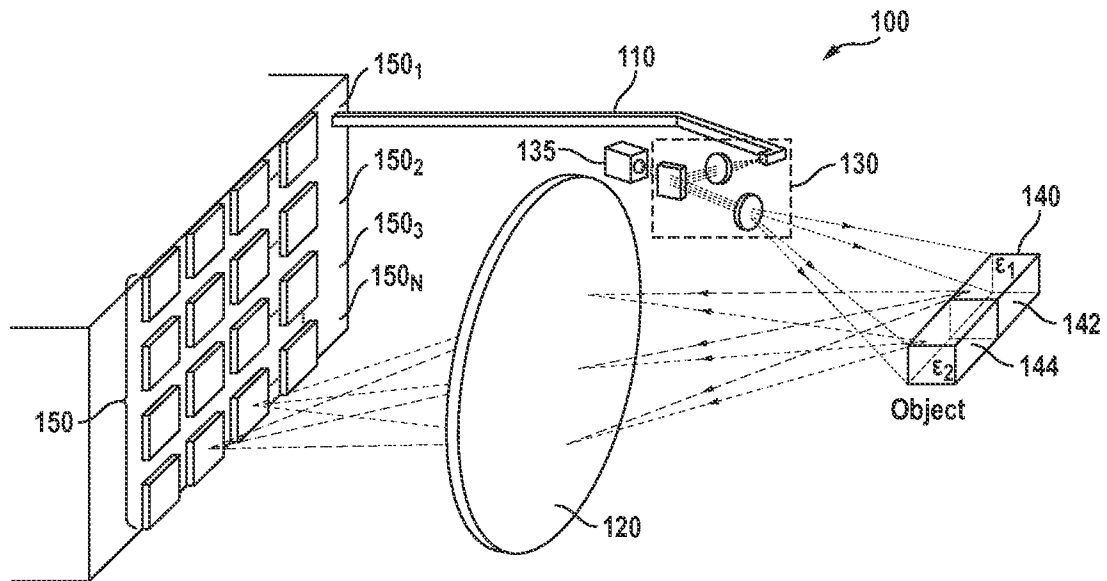


FIG. 5

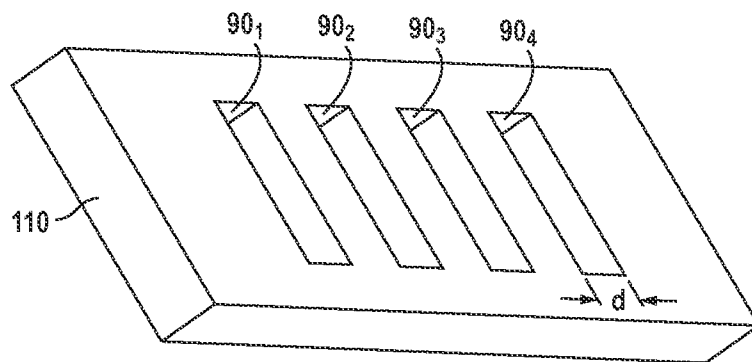


FIG. 6

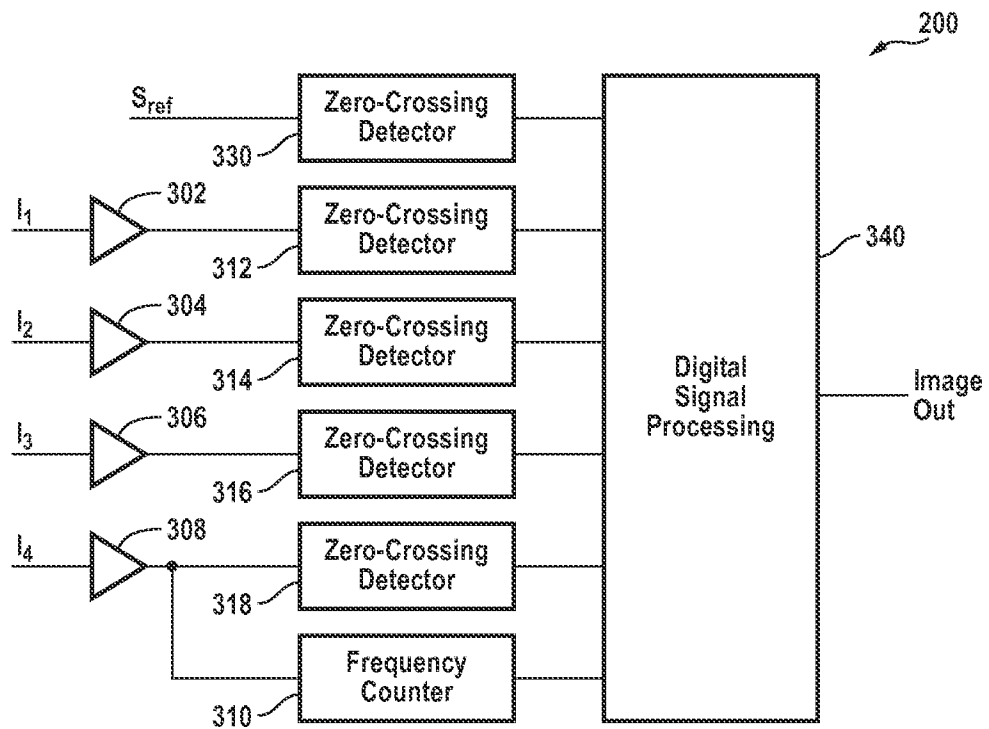


FIG. 7

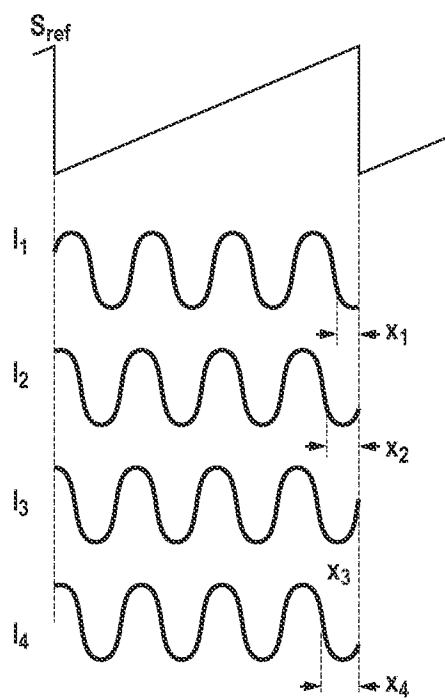


FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/059823**A. CLASSIFICATION OF SUBJECT MATTER****H04N 13/02(2006.01)i, H04N 5/225(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04N 13/02; G01B 11/24; G02B 27/42; G01C 3/08; G03B 15/00; G01B 9/02; H04N 5/225

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords:coherent, pixel, focus, signal, camera, target, combine, split, laser, photodiode

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 2000-333206 A (OLYMPUS OPTICAL CO., LTD.) 30 November 2000 See abstract; paragraphs 13, 15-17; figure 1; and claims 1, 3.	1-3,9,12-15,21,24
A		4-8,10-11,16-20,22-23
Y	US 5436462 A (C. GREGORY HULL-ALLEN) 25 July 1995 See column 3, lines 59-63; column 4, lines 66-68; column 6, lines 46-49; figure 4; and claims 1, 12.	1-3,9,12-15,21,24
A	KR 10-0406169 B1 (KOREA ELECTRIC POWER CORPORATION) 17 November 2003 See page 3; figure 4; and claims 1-2.	1-24
A	US 2005-0140982 A (ZHONGPING CHEN et al.) 30 June 2005 See paragraphs 52-54; figure 1C; and claim 1.	1-24
A	US 2010-0045966 A1 (MARIE ASTRID CAUQUY et al.) 25 February 2010 See paragraphs 21-24; figure 1; and claim 1.	1-24



Further documents are listed in the continuation of Box C.



See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search

23 December 2013 (23.12.2013)

Date of mailing of the international search report

23 December 2013 (23.12.2013)

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2013/059823

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