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APPLICATION NUMBER: *62/940,790*
FILING DATE: *November 26, 2019*
RELATED PCT APPLICATION NUMBER: *PCT/US20/25042*

THE COUNTRY CODE AND NUMBER OF YOUR PRIORITY APPLICATION, TO BE USED FOR FILING ABROAD UNDER THE PARIS CONVENTION, IS *US62/940,790*

Certified by

Andrei Iancu

Under Secretary of Commerce
for Intellectual Property
and Director of the United States
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PTO/AIA/14 (02-18)
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U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	35703-45208/US
	Application Number	
Title of Invention	ON-CHIP COHERENT PIXEL FOR FREQUENCY MODULATED CONTINUOUS WAVE LIDAR APPLICATIONS	

The application data sheet is part of the provisional or nonprovisional application for which it is being submitted. The following form contains the bibliographic data arranged in a format specified by the United States Patent and Trademark Office as outlined in 37 CFR 1.76.
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Inventor Information:

Inventor 1 Remove

Legal Name

Prefix	Given Name	Middle Name	Family Name	Suffix
	Andrew	Steil	Michaels	

Residence Information (Select One) ● US Residency Non US Residency Active US Military Service

City	Santa Clara	State/Province	CA	Country of Residence	US

Mailing Address of Inventor:

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Address 2	4701 Patrick Henry Dr #18

City	Santa Clara	State/Province	CA
Postal Code	95054	Country	US

Inventor 2 Remove

Legal Name

Prefix	Given Name	Middle Name	Family Name	Suffix
	Amir		Hosseini	

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City	Santa Clara	State/Province	CA	Country of Residence	US

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Postal Code	95054	Country	US

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City	Santa Clara	**State/Province**	CA
Postal Code	95054	**Country**	US

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Customer Number	00758		
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Application Information:

Title of the Invention	ON-CHIP COHERENT PIXEL FOR FREQUENCY MODULATED CONTINUOUS WAVE LIDAR APPLICATIONS		
Attorney Docket Number	35703-45208/US	**Small Entity Status Claimed**	☒
Application Type	Provisional		
Subject Matter	Utility		
Total Number of Drawing Sheets (if any)	3	**Suggested Figure for Publication (if any)**	

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For the purposes of a filing date under 37 CFR 1.53(b), the description and any drawings of the present application are replaced by this reference to the previously filed application, subject to conditions and requirements of 37 CFR 1.57(a).

Application number of the previously filed application	Filing date (YYYY-MM-DD)	Intellectual Property Authority or Country

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☐ Request Early Publication (Fee required at time of Request 37 CFR 1.219)

☐ **Request Not to Publish.** I hereby request that the attached application not be published under 35 U.S.C. 122(b) and certify that the invention disclosed in the attached application **has not and will not** be the subject of an application filed in another country, or under a multilateral international agreement, that requires publication at eighteen months after filing.

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Application Number	Continuity Type	Prior Application Number	Filing or 371(c) Date (YYYY-MM-DD)

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Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications

☐ This application (1) claims priority to or the benefit of an application filed before March 16, 2013 and (2) also contains, or contained at any time, a claim to a claimed invention that has an effective filing date on or after March 16, 2013.
NOTE: By providing this statement under 37 CFR 1.55 or 1.78, this application, with a filing date on or after March 16, 2013, will be examined under the first inventor to file provisions of the AIA.

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If the applicant is the inventor (or the remaining joint inventor or inventors under 37 CFR 1.45), this section should not be completed. The information to be provided in this section is the name and address of the legal representative who is the applicant under 37 CFR 1.43; or the name and address of the assignee, person to whom the inventor is under an obligation to assign the invention, or person who otherwise shows sufficient proprietary interest in the matter who is the applicant under 37 CFR 1.46. If the applicant is an applicant under 37 CFR 1.46 (assignee, person to whom the inventor is obligated to assign, or person who otherwise shows sufficient proprietary interest) together with one or more joint inventors, then the joint inventor or inventors who are also the applicant should be identified in this section.

Clear

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Person to whom the inventor is obligated to assign.	Person who shows sufficient proprietary interest	

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Name of the Deceased or Legally Incapacitated Inventor:

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Address 2			
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Country		Postal Code	
Phone Number		Fax Number	
Email Address			

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Country i		Postal Code	
Phone Number		Fax Number	
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Signature:

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Signature	/Michael W. Farn/			Date (YYYY-MM-DD)	2019-11-26
First Name	Michael W.	Last Name	Farn	Registration Number	41,015

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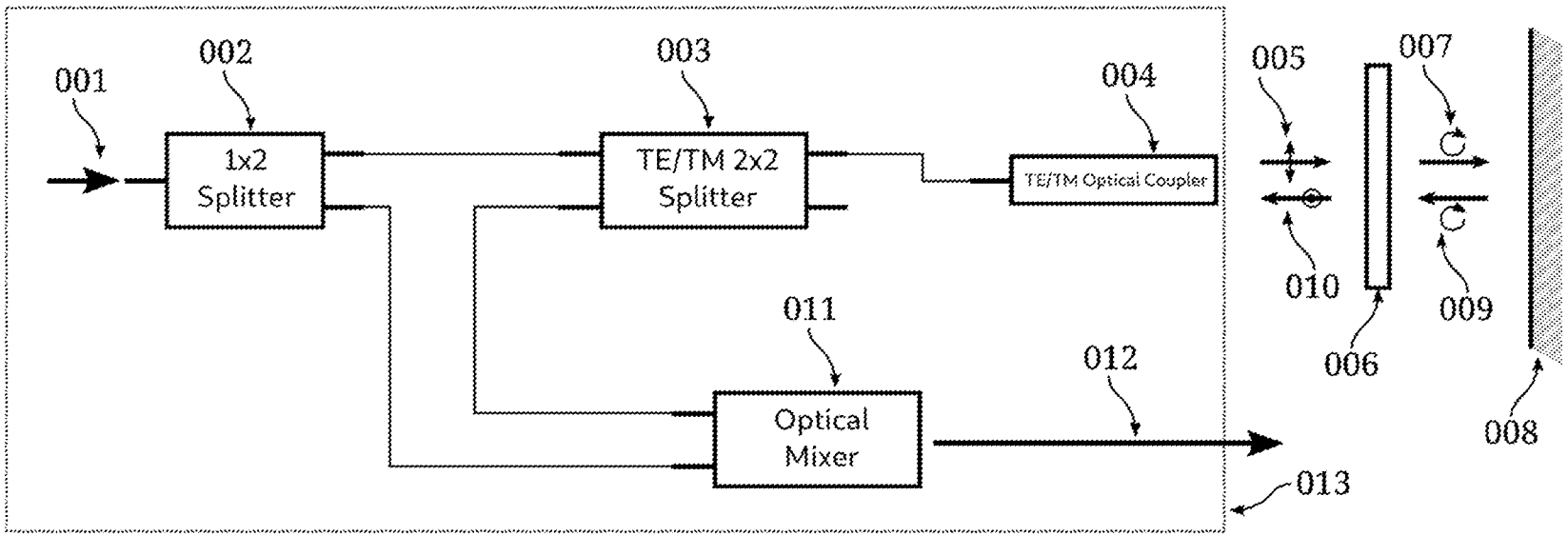
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002
1x2
Splitter
003
TE/TM 2x2
Splitter
004
TE/TM Optical Coupler
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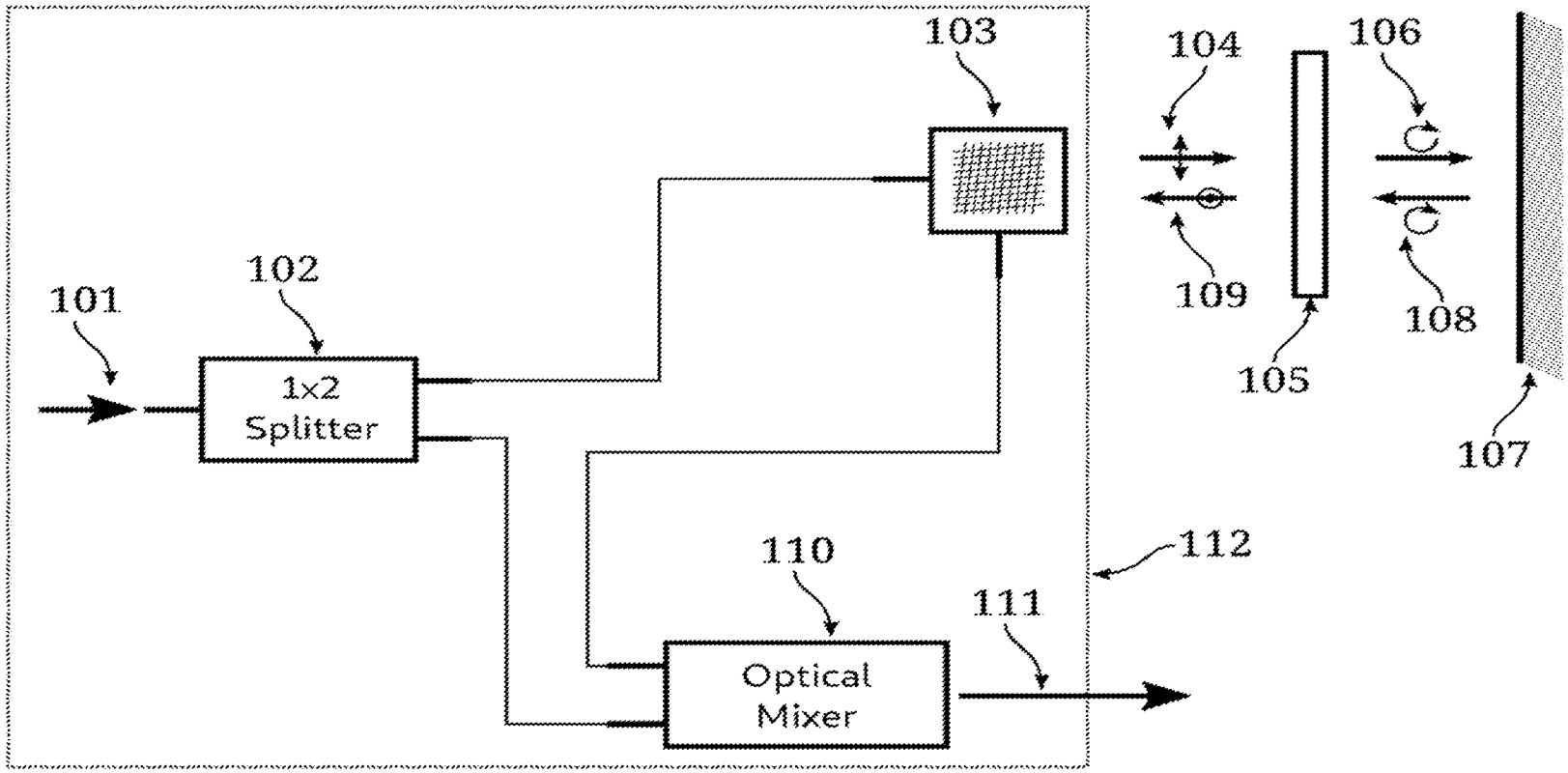
012
Optical
Mixer
013

Figure 1


103
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Splitter
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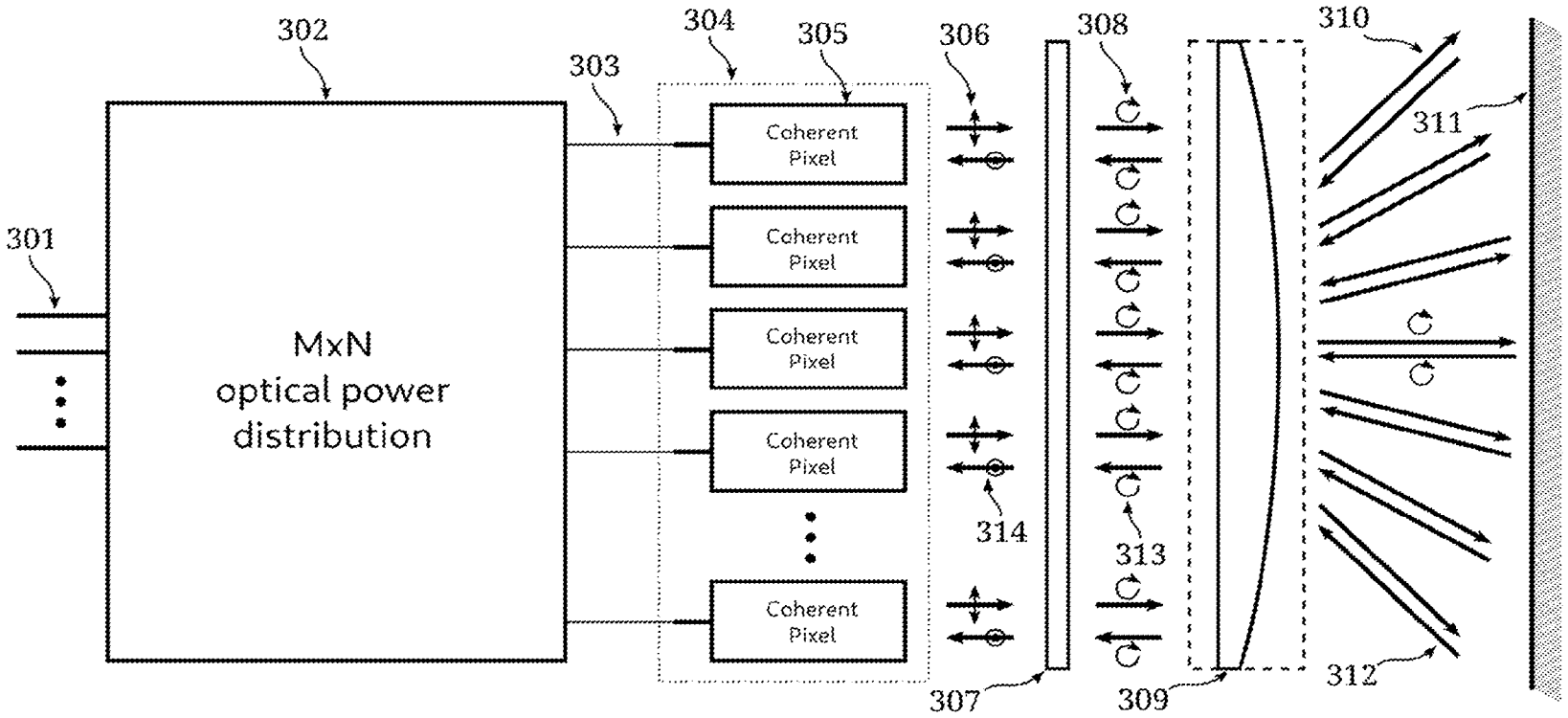
Figure 2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311
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Figure 3

ON-CHIP COHERENT PIXEL FOR FREQUENCY MODULATED CONTINUOUS WAVE LIDAR APPLICATIONS

BACKGROUND

[0001] The present invention is in the technical field of solid-state LIDAR.

[0002] Frequency Modulated Continuous Wave (FMCW) lidars directly measure range and velocity of an object by directing a frequency modulated, collimated light beam at the target. The light that is reflected from the object, Signal, is mixed with a tapped version of the beam, referred to as the local oscillator (LO). The frequency of the resulting beat tone is proportional to the distance of the object from the LIDAR system once corrected for doppler shift which may be determined by a second measurement. The two measurements, which may or may not be performed at the same time, provide both range and velocity information.

[0003] The module, where LO is tapped from input optical source and LO and Signal are mixed, is referred to as the Coherent Pixel.

[0004] FMCW LIDAR systems implemented using optical fibers and discrete optical components, such as optical interferometers, optical delay lines, and optical circulators are bulky, costly and unreliable for a wide range of applications, such as automotive and robotics.

[0005] Solid-state LIDARs overcome these issues by integrating the above-mentioned optical components as well as the required optoelectronic components, such as photodiodes and optical phase-shifters on a single semiconductor chip.

[0006] Conventionally, fiber-based optical circulators enable coaxial operation, where the beam shined on the target and the reflected optical signal share the same optical path and an optical circulator separates the out-going and in-coming beams inside the coherent pixel. Without a coaxial setup, the in-coming and out-going must be perfectly aligned or the received signal strength can be significantly degraded. Such alignment requirement creates manufacturability and reliability challenges.

[0007] Optical circulators are non-reciprocal optics requiring magnetic materials that are not typically available in conventional solid-state fabrication processes.

SUMMARY

[0008] Non-reciprocal optical components and optical polarization manipulating components, such as polarization separators/combiners and polarization rotators, may be included on Photonic Integrated Chips (PICs).

[0009] One aspect of the present invention is an efficient coherent pixel that uses a quasi on-chip circulator enabled by polarization diversity implemented on a PIC.

[0010] Two orthogonal optical polarizations are used for incoming and outgoing beams and they are separated inside the coherent pixel using an on-chip polarization splitter.

[0011] Multiple coherent pixels can be combined beneath a lens to form a focal plane array (FPA) which takes advantage of the quasi-circulator behavior of the coherent pixels described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] Figure 1 shows a diagram of the first embodiment of a coherent pixel which utilizes two polarizations of light to improve the performance of integrated FMCW LiDAR systems.

[0013] Input light (001) originating from a laser enters the coherent pixel and is split by a X/(1-X) splitter (002). X% of the light leaves the top port of the splitter, which constitutes the TX signal, and (1-X)% of the light leaves the bottom port of the splitter, which constitutes the local oscillator (LO) signal. Depending on the system parameters, an optimal splitting ratio may be chosen.

[0014] The TX signal enters a polarization splitter (003) which separates transverse electric (TE) and transverse magnetic (TM) polarized light. As an example, we will assume that the input

light in Figure 1 is TE-polarized. TM-polarized light can be used without modification of this idea.

[0015] Because the TX signal light is TE polarized, the light is coupled to the top port on the right-hand side of (003). Were the light TM polarized, it would leave through the bottom port on the right-hand side of (003).

[0016] The TX signal leaving the polarization splitter (003) enters a polarization-insensitive free-space coupler (004) which generates a free-space beam of light (005) that has a linear polarization matching the TE field of the preceding optical circuit (013).

[0017] The free-space beam propagates through a quarter-wave plate (006) which converts the linearly polarized beam of light to a circularly polarized beam of light (007).

[0018] The now-circularly-polarized light (007) propagates over a distance, which delays the light relative to the LO signal. This beam reflects off of a target surface (008), producing a reflected beam of light (009). Depending on the surface properties, this reflected beam may maintain its circular polarization or its polarization may become randomized.

[0019] The reflected beam of light (009) propagates back through free-space and a second time through the quarter waveplate (006). If the reflected beam (009) maintained its circular polarization, then the transmitted beam (010) will have a TM polarization (with respect to the originating transmitting and receiving optical circuit (013)). If the reflected beam (009) has a randomized polarization, then the transmitted beam (010) will have a random polarization.

[0020] The transmitted beam (010) is coupled back into the optical circuit (013) and propagates back into the top right-hand port of the polarization splitter (003). If the received beam of light is TM polarized, all of the light will be coupled to the bottom-left port of the polarization splitter (003). If the received beam is randomly polarized, then nominally half of the optical power will be coupled to the bottom-left port.

[0021] Light coupled to the bottom-left port of (003) enters the two-input-power optical mixer (011) which mixes the delayed received signal with the LO signal. The optical mixer generates one or more electrical signals (012) which are interpreted by the FMCW system.

[0022] In a second embodiment of the system, captured in Figure 2, the polarization splitter (003) and free-space coupler (004) are replaced by a single polarization-splitting vertical chip-to-free-space coupler (103). This free-space coupler takes TE light from its left input and generates a free space beam (104) with TE polarization. TM light incident on the coupler, meanwhile, is coupled into the bottom port of the optical device, which is connected to the optical mixer (110).

[0023] The functionality and behavior of the rest of the system in this second embodiment, labeled (101), (102), (104)-(112) is identical to (001), (002), and (005)-(013).

[0024] Figure 3 shows how the coherent pixels depicted in Figure 1 and Figure 2 can be used in a focal plane array (FPA) for FMCW applications. The focal plane array employs the coherent pixels to form a beam steering apparatus.

[0025] In Figure 3, light entering M input waveguides (301) is split between N output waveguides (303) by an MxN splitter (302).

[0026] The N output waveguides are connected to an array of a coherent pixels (304). This array can be one dimensional or two dimensional depending on if one dimensional or two dimensional beam steering is desired.

[0027] Each coherent pixel (305) emits TE-polarized light (306) that propagates through a quarter waveplate (307) which converts the light to circular polarization (308).

[0028] The circularly polarized light passes through a lens (309) which may consist of one or more lens elements. This lens converts the spatially-distributed circularly polarized beams of light to angled circularly polarized beams of light (310). The output angle of lens depends on the position of the input beam and the lens design, enabling beam steering operation.

[0029] The angled beams reflect off of a target (311). The diffuse reflected light returns towards the lens at the same angle (312). This reflected light may retain its circular polarization or become randomly polarized depending on the properties of the target.

[0030] The reflected beam of light passes back through the lens (309) which maps the angle of the beam to a specific position on the FPA.

[0031] The transmitted beam (313) passes back through the quarter wave plate (307). If the reflected light maintained its circular polarization, then the transmitted light (314) will be TM-polarized. If the reflected light is randomly polarized, then the transmitted light (314) will have a random polarization.

[0032] The transmitted light (314) passes is coupled back into the array of coherent pixels (304), which converts the light into an electrical signal as described previously.

CLAIMS

1. A method apprising any process in any disclosure herein, performed by any component in any disclosure herein.

2. An apparatus comprising any component in any disclosure herein, configured to perform any process in any disclosure herein.

3. A coherent pixel which implements quasi-circulator functionality using an integrated polarization splitter, an integrated polarization rotator, a polarization-independent edge coupler, and a quarter wave plate.

4. A coherent pixel which implements a quasi-circulator functionality using a two dimensional polarization-splitting vertical coupler and a quarter wave plate.

5. A focal plane array which employs a multitude of either type of previously-described coherent pixels for beam steering in FMCW lidar applications.

Electronic Acknowledgement Receipt

EFS ID:	37870734
Application Number:	62940790
International Application Number:	
Confirmation Number:	4640
Title of Invention:	ON-CHIP COHERENT PIXEL FOR FREQUENCY MODULATED CONTINUOUS WAVE LIDAR APPLICATIONS
First Named Inventor/Applicant Name:	Andrew Steil Michaels
Customer Number:	758
Filer:	Michael Wayne Farn
Filer Authorized By:	
Attorney Docket Number:	35703-45208/US
Receipt Date:	26-NOV-2019
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Application Type:	Provisional

Payment information:

Submitted with Payment	yes
Payment Type	DA
Payment was successfully received in RAM	$140
RAM confirmation Number	E2019APJ38097608
Deposit Account	
Authorized User	
The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows:	

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Application Data Sheet	45208_US_ADS.pdf	1255815 b23553b293d19b7366b51823b6421810a308a1a2	no	9
Warnings:					
Information:					
2	Drawings-other than black and white line drawings	45208_US_FIGURES.pdf	605394 6f3dea189e7c1248dc7aee7e2f5ca930fb634d05	no	3
Warnings:					
Information:					
3		45208_US_SPECIFICATION.pdf	701383 fea8dc79f3ee894470ca20dd88d91eb1425ba41c	yes	6

Multipart Description/PDF files in .zip description

Document Description	Start	End
Specification	1	5
Claims	6	6

Warnings:					
Information:					
4	Fee Worksheet (SB06)	fee-info.pdf	29937 58a26bc95e5c5780c40b3da0feb133ad7bd879d5	no	2
Warnings:					
Information:					
		Total Files Size (in bytes):	2592529		

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New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

DocCode – SCORE

SCORE Placeholder Sheet for IFW Content

Application Number: 62940790 Document Date: 11/26/2019

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