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International application number:	<b>PCT/US2020/025042</b>
International filing date:	<b>26 March 2020 (26.03.2020)</b>
Document type:	<b>Certified copy of priority document</b>
Document details:	Country/Office: <b>US</b>
	Number: <b>62/940,790</b>
	Filing date: <b>26 November 2019 (26.11.2019)</b>
Date of receipt at the International Bureau:	<b>17 April 2020 (17.04.2020)</b>

Remark: Priority document submitted or transmitted to the International Bureau in compliance with Rule 17.1(a),(b) or (b-bis)

1064140

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*April 16, 2020*

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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

*Andreea Iancu*

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Patent and Trademark Office

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<b>Application Data Sheet 37 CFR 1.76</b>		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. This document may be completed electronically and submitted to the Office in electronic format using the Electronic Filing System (EFS) or the document may be printed and included in a paper filed application.			

### Secrecy Order 37 CFR 5.2:

Portions or all of the application associated with this Application Data Sheet may fall under a Secrecy Order pursuant to 37 CFR 5.2 (Paper filers only. Applications that fall under Secrecy Order may not be filed electronically.)

### Inventor Information:

Inventor 1					Remove
Legal Name					
Prefix	Given Name	Middle Name	Family Name	Suffix	
	Andrew	Steil	Michaels		
Residence Information (Select One) <input checked="" type="radio"/> US Residency <input type="radio"/> Non US Residency <input type="radio"/> Active US Military Service					
City	Santa Clara	State/Province	CA	Country of Residence	US

#### Mailing Address of Inventor:

Address 1	OURS Technology Inc.				
Address 2	4701 Patrick Henry Dr #18				
City	Santa Clara	State/Province	CA		
Postal Code	95054	Country i	US		

Inventor 2					Remove
Legal Name					
Prefix	Given Name	Middle Name	Family Name	Suffix	
	Amir		Hosseini		
Residence Information (Select One) <input checked="" type="radio"/> US Residency <input type="radio"/> Non US Residency <input type="radio"/> Active US Military Service					
City	Santa Clara	State/Province	CA	Country of Residence	US

#### Mailing Address of Inventor:

Address 1	OURS Technology Inc.				
Address 2	4701 Patrick Henry Dr #18				
City	Santa Clara	State/Province	CA		
Postal Code	95054	Country i	US		

Inventor 3					Remove
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	Sen		Lin		
Residence Information (Select One) <input checked="" type="radio"/> US Residency <input type="radio"/> Non US Residency <input type="radio"/> Active US Military Service					

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City	Santa Clara	State/Province	CA	Country of Residence <sup>i</sup>	US
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**Mailing Address of Inventor:**

Address 1	OURS Technology Inc.				
Address 2	4701 Patrick Henry Dr #18				
City	Santa Clara	State/Province	CA		
Postal Code	95054	Country <sup>i</sup>	US		

All Inventors Must Be Listed - Additional Inventor Information blocks may be generated within this form by selecting the **Add** button.

**Correspondence Information:**

Enter either Customer Number or complete the Correspondence Information section below. For further information see 37 CFR 1.33(a).

An Address is being provided for the correspondence information of this application.

Customer Number	00758		
Email Address	ptoc@fenwick.com	<input type="button" value="Add Email"/>	<input type="button" value="Remove Email"/>

**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	<input checked="" type="checkbox"/>
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 <sup>i</sup>

**Publication Information:**

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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This section allows for the applicant to either claim benefit under 35 U.S.C. 119(e), 120, 121, 365(c), or 386(c) or indicate National Stage entry from a PCT application. Providing benefit claim information in the Application Data Sheet constitutes the specific reference required by 35 U.S.C. 119(e) or 120, and 37 CFR 1.78.

When referring to the current application, please leave the "Application Number" field blank.

Prior Application Status				<input type="button" value="Remove"/>
Application Number	Continuity Type	Prior Application Number	Filing or 371(c) Date (YYYY-MM-DD)	
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Application Number	Country <sup>i</sup>	Filing Date (YYYY-MM-DD)	Access Code <sup>i</sup> (if applicable)	<input type="button" value="Remove"/>
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## Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications

<input type="checkbox"/>	<p>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.</p> <p>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.</p>
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## Authorization or Opt-Out of Authorization to Permit Access:

When this Application Data Sheet is properly signed and filed with the application, applicant has provided written authority to permit a participating foreign intellectual property (IP) office access to the instant application-as-filed (see paragraph A in subsection 1 below) and the European Patent Office (EPO) access to any search results from the instant application (see paragraph B in subsection 1 below).

Should applicant choose not to provide an authorization identified in subsection 1 below, applicant **must opt-out** of the authorization by checking the corresponding box A or B or both in subsection 2 below.

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**A. Priority Document Exchange (PDX)** - Unless box A in subsection 2 (opt-out of authorization) is checked, the undersigned hereby **grants the USPTO authority** to provide the European Patent Office (EPO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO), the State Intellectual Property Office of the People's Republic of China (SIPO), the World Intellectual Property Organization (WIPO), and any other foreign intellectual property office participating with the USPTO in a bilateral or multilateral priority document exchange agreement in which a foreign application claiming priority to the instant patent application is filed, access to: (1) the instant patent application-as-filed and its related bibliographic data, (2) any foreign or domestic application to which priority or benefit is claimed by the instant application and its related bibliographic data, and (3) the date of filing of this Authorization. See 37 CFR 1.14(h) (1).

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<b>Application Data Sheet 37 CFR 1.76</b>	Attorney Docket Number	35703-45208/US
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**Applicant Information:**

Providing assignment information in this section does not substitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

<b>Applicant</b> 1	<input type="button" value="Remove"/>			
<p>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.</p>				
<input type="button" value="Clear"/>				
Assignee	Legal Representative under 35 U.S.C. 117	Joint Inventor		
Person to whom the inventor is obligated to assign.		Person who shows sufficient proprietary interest		
If applicant is the legal representative, indicate the authority to file the patent application, the inventor is:				
<div style="border: 1px solid black; height: 20px; width: 100%;"></div>				
Name of the Deceased or Legally Incapacitated Inventor: <input style="width: 90%;" type="text"/>				
If the Applicant is an Organization check here. <input type="checkbox"/>				
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<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
<b>Mailing Address Information For Applicant:</b>				
Address 1	<input type="text"/>			
Address 2	<input type="text"/>			
City	<input type="text"/>	State/Province	<input type="text"/>	
Country	<input type="text"/>	Postal Code	<input type="text"/>	
Phone Number	<input type="text"/>	Fax Number	<input type="text"/>	
Email Address	<input type="text"/>			
Additional Applicant Data may be generated within this form by selecting the Add button.				<input type="button" value="Add"/>

**Assignee Information including Non-Applicant Assignee Information:**

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

<b>Assignee</b>	1
-----------------	---

Complete this section if assignee information, including non-applicant assignee information, is desired to be included on the patent application publication. An assignee-applicant identified in the "Applicant Information" section will appear on the patent application publication as an applicant. For an assignee-applicant, complete this section only if identification as an assignee is also desired on the patent application publication.

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Address 2				
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Country <sup>i</sup>		Postal Code		
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See 37 CFR 1.4(d) for the manner of making signatures and certifications.

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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<b>Application Data Sheet 37 CFR 1.76</b>		Attorney Docket Number	35703-45208/US
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This collection of information is required by 37 CFR 1.76. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 23 minutes to complete, including gathering, preparing, and submitting the completed application data sheet form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

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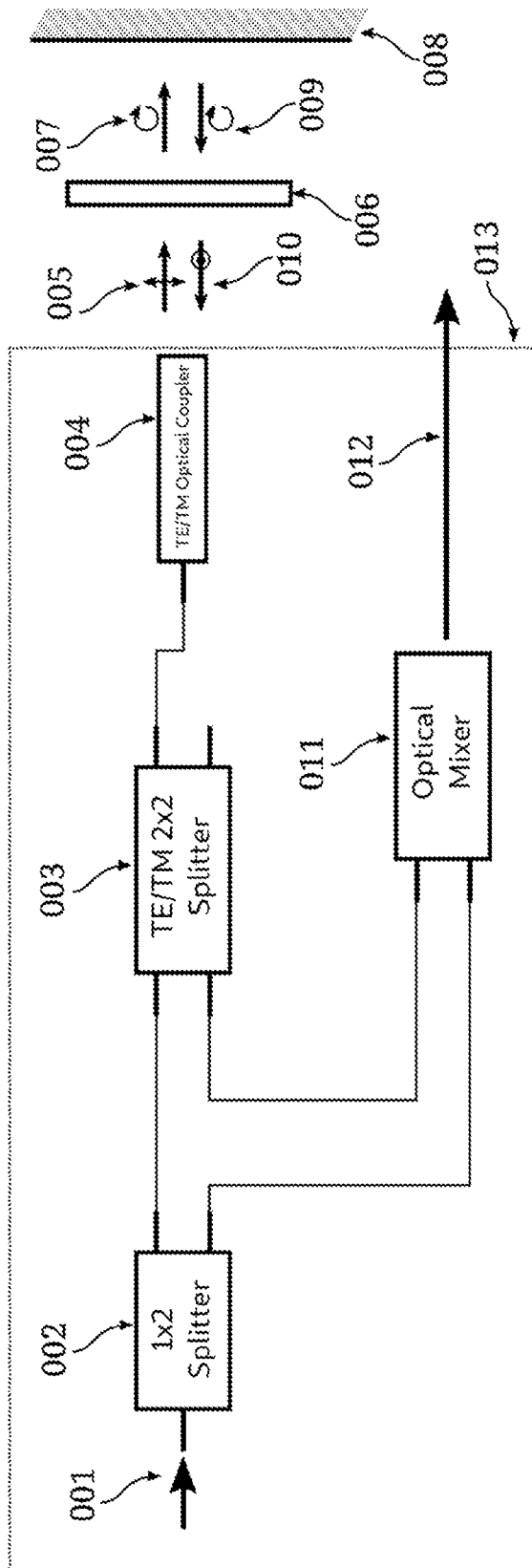


Figure 1

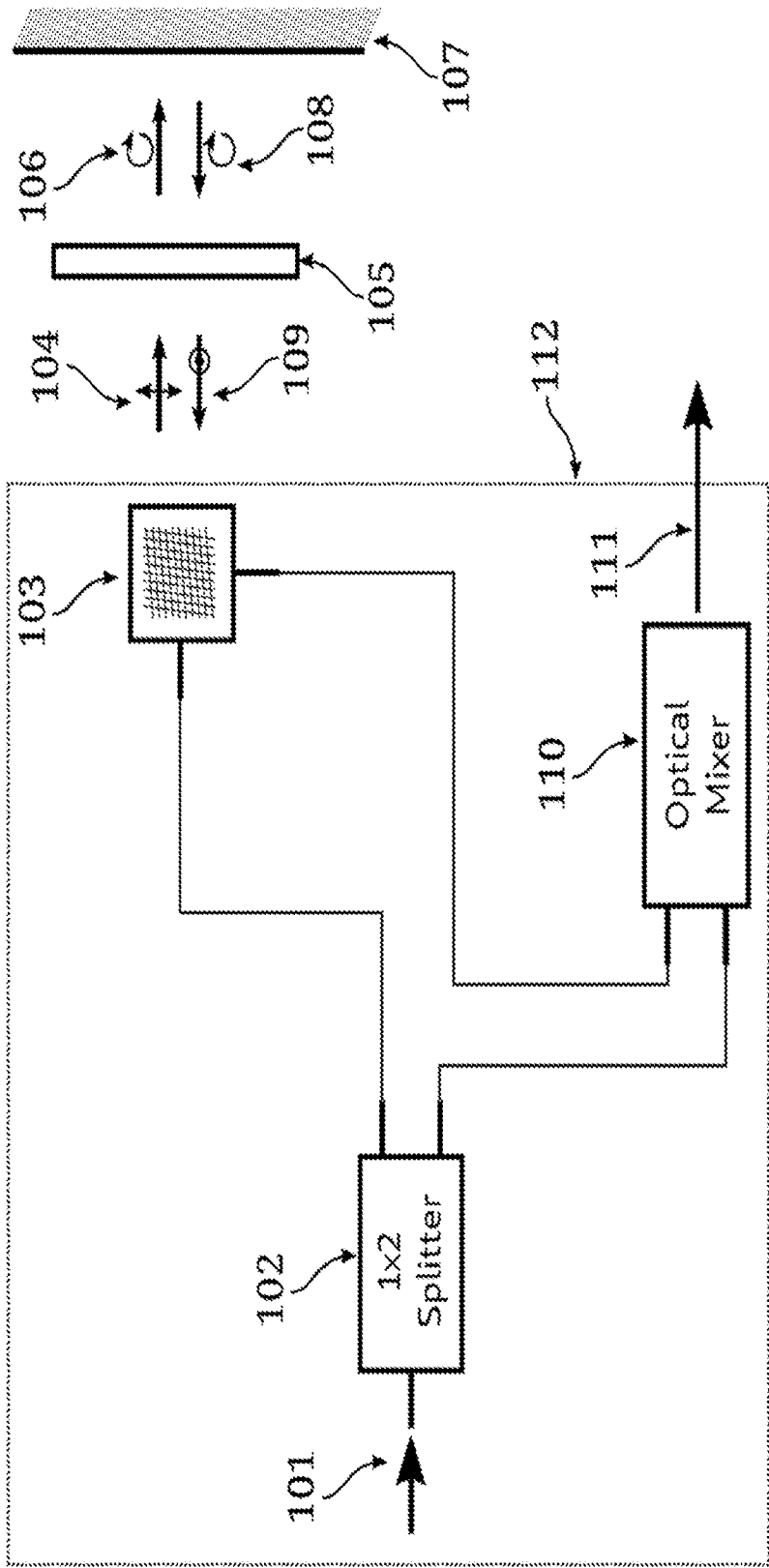


Figure 2

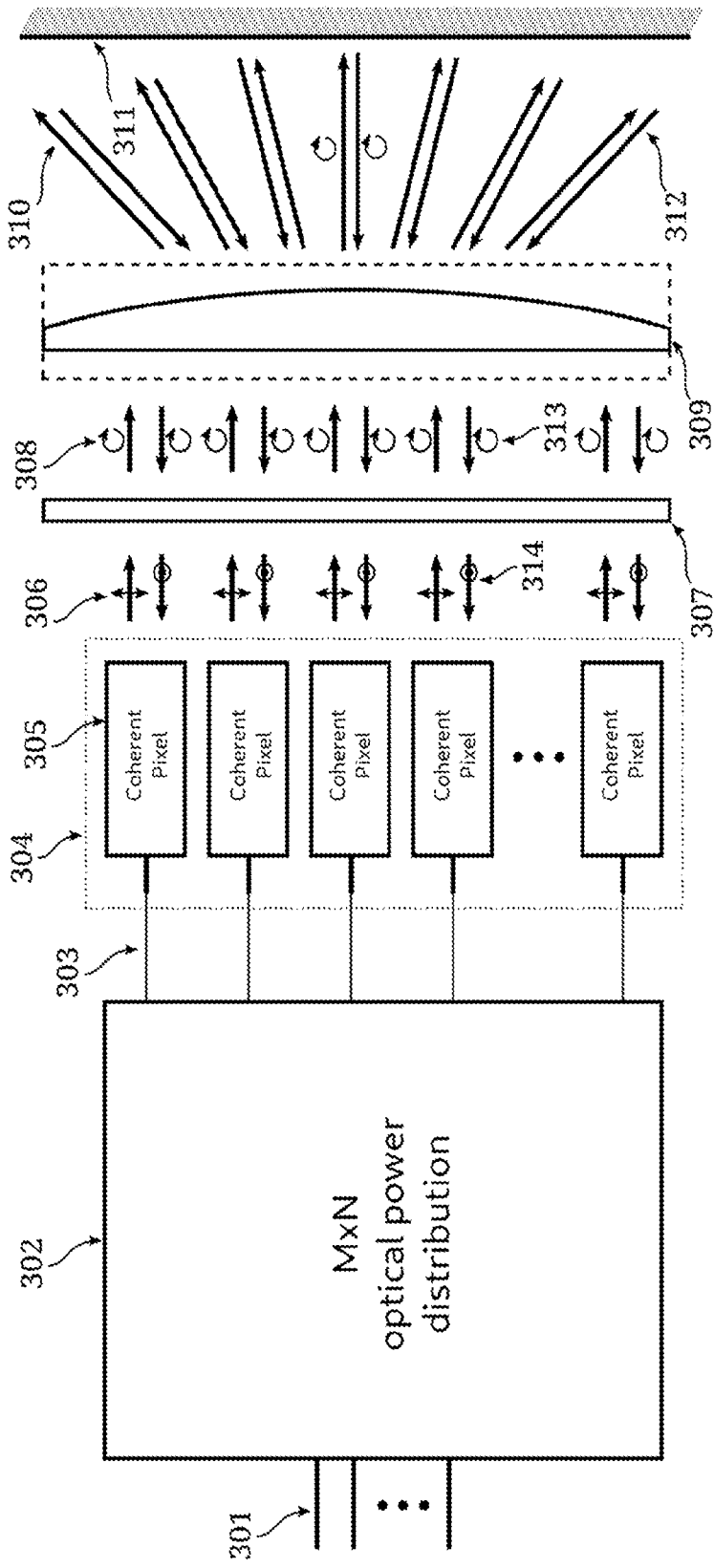


Figure 3

# 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

<b>EFS ID:</b>	37870734
<b>Application Number:</b>	62940790
<b>International Application Number:</b>	
<b>Confirmation Number:</b>	4640
<b>Title of Invention:</b>	ON-CHIP COHERENT PIXEL FOR FREQUENCY MODULATED CONTINUOUS WAVE LIDAR APPLICATIONS
<b>First Named Inventor/Applicant Name:</b>	Andrew Steil Michaels
<b>Customer Number:</b>	758
<b>Filer:</b>	Michael Wayne Farn
<b>Filer Authorized By:</b>	
<b>Attorney Docket Number:</b>	35703-45208/US
<b>Receipt Date:</b>	26-NOV-2019
<b>Filing Date:</b>	
<b>Time Stamp:</b>	19:37:38
<b>Application Type:</b>	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:

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1	Application Data Sheet	45208_US_ADS.pdf	1255815	no	9
			b23553b293d19b7366b51623b6421810a308a1a2		
<b>Warnings:</b>					
<b>Information:</b>					
2	Drawings-other than black and white line drawings	45208_US_FIGURES.pdf	605394	no	3
			6f3dea189e7c1248dc7aee7e2f5ca930fb634d05		
<b>Warnings:</b>					
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3		45208_US_SPECIFICATION.pdf	701383	yes	6
			fea8dc79f3ee894470ca20dd88d91eb1425ba41c		
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	<b>Document Description</b>		<b>Start</b>	<b>End</b>	
	Specification		1	5	
	Claims		6	6	
<b>Warnings:</b>					
<b>Information:</b>					
4	Fee Worksheet (SB06)	fee-info.pdf	29937	no	2
			58a26bc95e5c5780c40b3da0feb133ad7bd879d5		
<b>Warnings:</b>					
<b>Information:</b>					
<b>Total Files Size (in bytes):</b>			2592529		

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**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**

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Application Number: 62940790

Document Date: 11/26/2019

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