they may not directly measure the time-of-flight of pulses of laser light. For many LIDAR applications, it is beneficial for physical sizes of transmitters and receivers to small and compact, and at the same time relatively low in cost. For applications where objects must be sensed with accuracy at long distances, it is beneficial to increase or maximize the number of photons emitted by the transmitter and reflected back toward the receiver while keeping laser energy emissions within mandated safety limits.

[0007] Micro-optical systems are systems that include miniaturized, optical components that are typically between a few micrometers and a millimeter in size. Micro-optical receivers arrayed adjacent to each other are susceptible to crosstalk. Stray light caused by roughness of optical surfaces, imperfections in transparent media, back reflections, etc., may be generated at various features within the receiver channel or external to receiver channel. When multiple receiver channels are arrayed adjacent to one another, this stray light in one receiver channel may be absorbed by a photosensor in another channel, thereby contaminating the timing, phase, or other information inherent to photons. Minimizing crosstalk is especially important in active-illumination systems. Light reflected from a nearby retro-reflector (e.g. a license plate) may be thousands or millions of time more intense than light reflected from a distant, dark, lambertian surface (e.g. black cotton clothing). Thus, the stray light photons from a retro-reflector could vastly outnumber photons reflected from other surfaces in nearby photosensors if crosstalk is not minimized. This can result in the inability of a LIDAR system to detect dark objects that occupy fields of view near the field of view occupied by a retro-reflector.

SUMMARY

[0008] Embodiments of the disclosure provide optical imager systems that achieve wide field-of-view, narrowband imaging with micro-optic receiver channel arrays that minimize crosstalk and allow tight spectral selectivity that is uniform across the receiver channel array. Some optical imager systems according to embodiments of the disclosure can include a light transmission module that provides enhanced spot illumination such that a power level of light returning to a light sensing module is increased, while at the same time improving the spatial resolution of the measured image.

[0009] According to a first aspect of the present disclosure, there is provided an optical system for performing distance measurements including a bulk transmitter optic, an illumination source, and a micro-optic channel array disposed between the illumination source and the bulk transmitter optic. The illumination source includes a plurality of light emitters aligned to project discrete beams of light through the bulk transmitter optic into a field ahead of the optical system. The micro-optic channel array defines a plurality of micro-optic channels where each micro-optic channel includes a micro-optic lens spaced apart from a light emitter from the plurality of light emitters with the micro-optic lens being configured to receive a light cone from the light emitter and generate a reduced-size spot image of the emitter at a focal point displaced from the emitter at a location between the emitter and the bulk transmitter optic. The micro-optic lens for each channel can be configured to receive a light cone from a light emitter and generate a reduced-size real spot image of the emitter at a focal point between the micro-optic lens and the bulk transmitter optic. A divergence of the light cone from the light emitter can be less than a divergence of a light cone from the second optical surface of the micro-optic lens for generating the reduced-size real spot image

[0010] According to a second aspect of the present disclosure, there is provided an optical system for performing distance measurements including a light emission system and a light detection system. The light emission system includes a bulk transmitter optic, an illumination source comprising a plurality of light emitters aligned to project discrete beams of light through the bulk transmitter optic into a field ahead of the optical system, and a micro-optic channel array disposed between the illumination source and the bulk transmitter optic. The micro-optic channel array defines a plurality of micro-optic channels where each micro-optic channel includes a micro-optic lens spaced apart from a light emitter from the plurality of light emitters with the micro-optic lens being configured to receive a light cone from the light emitter and generate a reduced-size spot image of the emitter at a focal point displaced from the emitter at a location between the emitter and the bulk transmitter optic. The light detection system includes a bulk receiver optic configured to receive the discrete beams of light from the field, and an optical assembly having a plurality of micro-optic receiver channels defining a plurality of discrete, non-overlapping fields of view in the field. The optical assembly includes: an aperture layer having a plurality of discrete apertures arranged along a focal plane of the bulk receiver optic; an array of photosensors

disposed behind the aperture layer; and a plurality of lenses positioned between the aperture layer and the array of photosensors.

[0011] According to a third aspect of the present disclosure, there is provided an optical system for performing distance measurements including a stationary housing having an optically transparent window, and a light ranging device disposed within the housing. The light ranging device includes an optical transmitter coupled to a platform. The optical transmitter includes a bulk transmitter optic, an illumination source, and a micro-optic channel array disposed between the illumination source and the bulk transmitter optic. The illumination source including a plurality of light emitters aligned to project discrete beams of light through the bulk transmitter optic into a field ahead of the optical system. The micro-optic channel array can be disposed between the illumination source and the bulk transmitter optic, and the micro-optic channel array can define a plurality of micro-optic channels where each micro-optic channel can include a micro-optic lens spaced apart from a light emitter from the plurality of light emitters with the micro-optic lens being configured to receive a light cone from the light emitter and generate a reduced-size spot image of the emitter at a focal point displaced from the emitter at a location between the emitter and the bulk transmitter optic.

[0012] Disclosed herein is an optical system including a bulk receiver optic configured to receive light rays originating from a field external to the optical system, and an optical assembly having a plurality of micro-optic receiver channels defining a plurality of discrete, non-overlapping fields of view in the field. The optical assembly includes an aperture layer having a plurality of discrete apertures arranged along a focal plane of the bulk receiver optic, an array of photosensors disposed behind the aperture layer, and a non-uniform optical filter layer configured to allow different micro-optic channels to measure different ranges of wavelengths. The non-uniform optical filter can include a graduated optical filter that gradually increases in thickness in one dimension, or increases in thickness in a step-wise fashion in one direction such that each channel has a constant optical filter layer thickness, but where the thicknesses for different micro-optic channels are different.

[0013] Disclosed herein is an optical system including a bulk receiver optic configured to receive light from a field external to the optical system, an aperture layer disposed behind the bulk optic and including a plurality of apertures located at a focal plane of the bulk optic, a lens layer

including a plurality of collimating lenses having a focal length, the lens layer disposed behind the aperture layer and separated from the aperture layer by the focal length, a non-uniform optical filter layer behind the lens layer, and a photosensor layer including a plurality of photosensors. The aperture layer, lens layer, non-uniform optical filter layer and photosensor layer are arranged to form a plurality of micro-optic channels defining a plurality of discrete, non-overlapping fields of view in the field with each micro-optic channel in the plurality of micro-optic channels including an aperture from the plurality of apertures, a lens from the plurality of lenses, a filter from the filter layer, and a photosensor from the plurality of photosensors and being configured to communicate light incident from the bulk receiver optic to the photosensor of the micro-optic channel. The non-uniform optical filter layer is configured to allow different micro-optic channels to measure different ranges of wavelengths.

[0014] Disclosed herein is an optical system including a bulk receiver optic configured to receive light rays originating from a field external to the optical system, and an optical assembly having a plurality of micro-optic receiver channels defining a plurality of discrete, non-overlapping fields of view in the field. The optical assembly includes a monolithic ASIC including a processor, a memory, and a plurality of photosensors fabricated in the ASIC, an aperture layer having a plurality of discrete apertures arranged along a focal plane of the bulk receiver optic, the array of photosensors disposed behind the aperture layer; a plurality of lenses positioned between the aperture layer and the array of photosensors; and a non-uniform optical filter layer having different center wavelengths across its structure to allow at least two different micro-optic receiver channels to measure different ranges of wavelengths of light, wherein the aperture layer, plurality of lenses, and non-uniform optical filter layer are formed on the ASIC such that they form part of the monolithic structure of the ASIC.

[0015] Disclosed herein is an optical system for performing distance measurements including a stationary housing having an optically transparent window, a spinning light ranging device disposed within the housing, a motor disposed within the housing and operatively coupled to spin the light ranging device including the platform, optical transmitter, and optical receiver within the housing, and a system controller disposed within the housing, the system controller configured to control the motor and to start and stop light detection operations of the light ranging device. The light ranging device includes a platform, an optical transmitter coupled to the platform, and an

optical receiver coupled to the platform. The optical transmitter includes a bulk transmitter optic and a plurality of transmitter channels, each transmitter channel including a light emitter configured to generate and transmit a narrowband light through the bulk transmitter optic into a field external to the optical system. The optical receiver includes a bulk receiver optic and a plurality of micro-optic receiver channels, each micro-optic channel including an aperture coincident with a focal plane of the bulk receiver optic, an optical filter positioned along a path of light from the bulk receiver optic and axially aligned with the aperture, and a photosensor responsive to incident photons passed through the aperture and the optical filter.

[0016] Disclosed herein is an optical system for performing distance measurements including a stationary housing having a base, a top and an optically transparent window disposed between the base and the top, a spinning light ranging device disposed within the housing and aligned with the optically transparent window, a motor disposed within the housing and operatively coupled to spin the light ranging device including the platform, optical transmitter and optical receiver within the housing, and a system controller disposed within the housing, the system controller configured to control the motor and to start and stop light detection operations of the light ranging device. The light ranging device including a platform, an optical transmitter coupled to the platform, and an optical receiver coupled to the platform. The optical transmitter including an image-space telecentric bulk transmitter optic and a plurality of transmitter channels, each channel including a light emitter configured to generate and transmit a narrowband light through the bulk transmitter optic into a field external to the optical system. The optical receiver including an image-space telecentric bulk receiver optic and a plurality of micro-optic receiver channels, each micro-optic channel including an aperture coincident with a focal plane of the bulk receiver optic, a collimating lens behind the aperture, an optical filter behind the collimating lens and a photosensor responsive to incident photons passed through the aperture into the collimating lens and through the filter.

[0017] Disclosed herein is an optical system for performing distance measurements including a stationary housing having a base, a top and an optically transparent window disposed between the base and the top, a light ranging device disposed within the housing and aligned with the optically transparent window, a motor disposed within the housing and operatively coupled to spin the light ranging device within the housing; and a system controller disposed within the housing, the

system controller configured to control the motor and to start and stop light detection operations of the light ranging device. The light ranging device includes a platform, a plurality of vertical-cavity surface emitting lasers (VCSELs) arranged in an array, and an optical receiver coupled to the platform. Each VCSEL in the plurality of VCSELs are configured to generate and transmit discrete pulses of light into a field external to the optical system. The optical receiver including a bulk receiver optic, a plurality of photosensors, each photosensor comprising a plurality of single-photon avalanche diodes (SPADs) responsive to incident photons, and an optical filter disposed between the bulk receiver optic and the plurality of photosensors and configured to allow a band of light to pass through the filter to the plurality of photosensors while blocking light outside the band from reaching the plurality of photosensors.

[0018] Disclosed herein is an optical system for performing distance measurements including a rotatable platform, an optical transmitter coupled to the rotatable platform and comprising a bulk transmitter optic and a plurality of transmitter channels, an optical receiver coupled to the rotatable platform and comprising a bulk receiver optic and a plurality of micro-optic receiver channels, a motor disposed within the housing and operatively coupled to spin the platform, optical transmitter, and optical receiver, a system controller mounted to a stationary component of the optical system; and an optical communication link operatively coupled between the system controller and the optical receiver to enable the system controller to communicate with the optical receiver. Each transmitter channel includes a light emitter configured to generate and transmit a narrowband light through the bulk transmitter optic into a field external to the optical system. Each micro-optic channel includes an aperture coincident with a focal plane of the bulk receiver optic, an optical filter positioned along a path of light from the bulk receiver optic and axially aligned with the aperture, and a photosensor responsive to incident photons passed through the aperture and through the filter. The optical communication link can extend between the stationary component of the optical system and the rotatable platform to operatively couple the system controller with the optical receiver. The optical receiver can further include a collimating lens behind the aperture and directly coupled to the optical filter, the optical filter positioned behind the collimating lens.

[0019] Disclosed herein is an optical system for performing distance measurements including a rotatable platform, an optical transmitter coupled to the rotatable platform and comprising an

image-space telecentric bulk transmitter optic and a plurality of transmitter channels, an optical receiver coupled to the rotatable platform and comprising an image-space telecentric bulk receiver optic and a plurality of micro-optic receiver channels, a motor disposed within the housing and operatively coupled to spin the platform, optical transmitter and optical receiver, a system controller mounted to a stationary component of the optical system, and an optical communication link operatively coupled between the system controller and the optical receiver to enable the system controller to communicate with the optical receiver. Each transmitter channel includes a light emitter configured to generate and transmit a narrowband light through the bulk transmitter optic into a field external to the optical system. Each micro-optic channel includes an aperture coincident with a focal plane of the bulk receiver optic, a collimating lens behind the aperture, an optical filter behind the collimating lens and a photosensor responsive to incident photons passed through the aperture into the collimating lens and through the filter.

[0020] Disclosed herein is an optical system for performing distance measurements including a rotatable platform, a plurality of vertical-cavity surface emitting lasers (VCSELs) arranged in an array and coupled to the rotatable platform, an optical receiver coupled to the rotatable platform, a motor disposed within the housing and operatively coupled to spin the platform, the plurality of VCSELs and the optical receiver; a system controller mounted to a stationary component of the optical system, and an optical communication link operatively coupled between the system controller and the optical receiver to enable the system controller to communicate with the optical receiver. Each VCSEL in the plurality of VCSELs are configured to generate and transmit discrete pulses of light into a field external to the optical system. The optical receiver including a bulk receiver optic and a plurality of photosensors, each photosensor comprising a plurality of single-photon avalanche diodes (SPADs) responsive to incident photons.

[0021] Disclosed herein is an optical system for performing distance measurements including a bulk receiver optic, an aperture layer including a plurality of apertures, a first lens layer including a first plurality of lenses, an optical filter layer configured to receive light after it passes through the bulk receiver optic and pass a band of radiation while blocking radiation outside the band, and a photosensor layer including a plurality of photosensors, Each photosensor includes a plurality of photodetectors configured to detect photons, and a second plurality of lenses configured to focus incident photons received at the photosensor on the plurality of photodetectors. The optical

system inclufdes a plurality of receiver channels with each receiver channel in the plurality of receiver channels including an aperture from the plurality of apertures, a lens from the plurality of first lenses, an optical filter from the optical filter layer, and a photosensor from the plurality of photosensors, with the aperture for each channel defining a discrete, non-overlapping field of view for its respective channel. For each receiver channel in the plurality of receiver channels, there can be a one-to-one correspondence between the plurality of photodetectors and the second plurality of lenses in the photosensor for that channel, where each of the lenses in the second plurality of lenses can be configured to focus photons on its corresponding lens in the second plurality of lenses

[0022] Disclosed herein is an optical system for performing distance measurements including a light emission system and a light detection system. The light emission system including a bulk transmitter optic and an illumination source. The illumination source including a plurality of light emitters aligned to project discrete beams of light through the bulk transmitter optic into a field ahead of the optical system. The light detection system including a bulk receiver optic, an aperture layer including a plurality of apertures, a first lens layer including a first plurality of lenses, an optical filter layer configured to receive light after it passes through the bulk receiver optic and pass a band of radiation while blocking radiation outside the band, and a photosensor layer including a plurality of photosensors. Each photosensor includes a plurality of photodetectors configured to detect photons, and a second plurality of lenses configured to focus incident photons received at the photosensor on the plurality of photodetectors. The optical system includes a plurality of receiver channels with each receiver channel in the plurality of receiver channels including an aperture from the plurality of apertures, a lens from the plurality of first lenses, an optical filter from the optical filter layer, and a photosensor from the plurality of photosensors, with the aperture for each channel defining a discrete, non-overlapping field of view for its respective channel.

[0023] Disclosed herein is an optical system for performing distance measurements including a stationary housing having an optically transparent window, a light ranging device disposed within the housing and aligned with the optically transparent window, a motor disposed within the housing and operatively coupled to spin the light ranging device including the platform, optical transmitter, and optical receiver within the housing, and a system controller disposed within the

housing. The system controller configured to control the motor and to start and stop light detection operations of the light ranging device. The light ranging device including a platform, an optical transmitter coupled to the platform, an optical receiver coupled to the platform. The optical transmitter including a bulk transmitter optic and a plurality of transmitter channels, each transmitter channel including a light emitter configured to generate and transmit a narrowband light through the bulk transmitter optic into a field external to the optical system. The optical receiver including a bulk receiver optic, an aperture layer including a plurality of apertures, a first lens layer including a first plurality of lenses, an optical filter layer configured to receive light after it passes through the bulk receiver optic and pass a band of radiation while blocking radiation outside the band, and a photosensor layer including a plurality of photosensors. Each photosensor includes a plurality of photodetectors configured to detect photons, and a second plurality of lenses configured to focus incident photons received at the photosensor on the plurality of photodetectors. The optical system includes a plurality of receiver channels with each receiver channel in the plurality of receiver channels including an aperture from the plurality of apertures, a lens from the plurality of first lenses, an optical filter from the optical filter layer, and a photosensor from the plurality of photosensors, with the aperture for each channel defining a discrete, non-overlapping field of view for its respective channel.

[0024] A better understanding of the nature and advantages of embodiments of the present disclosure may be gained with reference to the following detailed description and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] FIG. 1 is a block diagram of an exemplary passive optical imager system, according to some embodiments of the present disclosure.

[0026] FIG. 2 is a simplified diagram of an exemplary light detection system for a passive optical imager system, according to some embodiments of the present disclosure.

CLAIMS

1. An optical system for performing distance measurements, the optical system comprising:

a bulk transmitter optic;

an illumination source comprising a plurality of light emitters aligned to project discrete beams of light through the bulk transmitter optic into a field ahead of the optical system; and

a micro-optic channel array disposed between the illumination source and the bulk transmitter optic, the micro-optic channel array defining a plurality of micro-optic channels, each micro-optic channel including a micro-optic lens spaced apart from a light emitter from the plurality of light emitters with the micro-optic lens being configured to receive a light cone from the light emitter and generate a reduced-size spot image of the emitter at a focal point displaced from the emitter at a location between the emitter and the bulk transmitter optic.

2. The optical system for performing distance measurements set forth in claim 1 wherein the bulk transmitter optic comprises one or more lenses configured as an image space telecentric lens in which the discrete beams of light output from the illumination source through the micro-optic channel array are parallel to each other.

3. The optical system for performing distance measurements set forth in claim 2 further comprising a light sensing module configured to detect photons emitted from the illumination source and reflected from surfaces within the field.

4. The optical system for performing distance measurements set forth in claim 3 wherein the light sensing module comprises:

a bulk receiver optic;

an aperture layer including a plurality of apertures;

a lens layer including a plurality of lenses; and

a photosensor layer including a plurality of photosensors, wherein the aperture layer, lens layer, and photosensor layer are arranged to form a plurality of receiver channels with each receiver channel in the plurality of receiver channels including an aperture from the plurality of apertures, a lens from the plurality of lenses and a photosensor from the plurality of

photosensors and being configured to communicate light incident from the bulk receiving optic to the photosensor of the receiver channel.

5. The optical system for performing distance measurements set forth in claim 4 wherein the illumination source is configured to selectively project the discrete beams of light through the bulk transmitter optic according to an illumination pattern that matches, in size and geometry across a range of distances from the system, the fields of view of the receiver channels.

6. The optical system for performing distance measurements set forth in claim 1 wherein the micro-optic lens for each channel is configured to receive a light cone from a light emitter and generate a reduced-size real spot image of the emitter at a focal point between the micro-optic lens and the bulk transmitter optic.

7. The optical system for performing distance measurements set forth in claim 6 wherein the micro-optic lens for each channel includes a first optical surface with an optical power on a side facing the light emitter and a second optical surface with an optical power on an opposing side facing away from the light emitter and wherein the reduced-size real spot image of the emitter is formed at a focal point after the first and second optical surfaces.

8. The optical system for performing distance measurements set forth in claim 7, wherein a divergence of the light cone from the light emitter is less than a divergence of a light cone from the second optical surface of the micro-optic lens for generating the reduced-size real spot image.

9. The optical system for performing distance measurements set forth in claim 7, wherein the micro-optic lens is separated from the illumination source to define an open space between the micro-optic lens and the illumination source.

10. The optical system for performing distance measurements set forth in claim 6 wherein the micro-optic lens for each channel includes an optical surface with an optical power on a side facing away from the light emitter and wherein the reduced-size real spot image of the emitter is formed at a focal point after the optical surface.

11. The optical system for performing distance measurements set forth in claim 6 wherein the optical surface includes a plurality of convex lenses positioned on a substrate, the substrate having a first surface upon which the optical surface is disposed and a second surface opposite of the first surface that is directly attached to a surface of the illumination source.

12. The optical system for performing distance measurements set forth in claim 1 wherein the micro-optic lens for each channel is configured to receive a light cone from a light emitter and generate a reduced-size virtual spot image of the emitter.

13. The optical system for performing distance measurements set forth in claim 12 wherein the micro-optic lens for each channel includes an optical surface with an optical power on a side facing away from the light emitter and wherein the reduced-size virtual spot image of the emitter is formed at a focal point within the respective channel.

14. The optical system for performing distance measurements set forth in claim 13 wherein the optical surface includes a plurality of concave surfaces formed on substrate, the substrate having a first surface upon which the optical surface is disposed and a second surface opposite of the first surface that is directly attached to a surface of the illumination source

15. The optical system for performing distance measurements set forth in claim 1 wherein the bulk transmitter optic comprises multiple aperture stops configured to reduce stray light emitted by the optical system.

16. An optical system for performing distance measurements, the optical system comprising:

a light emission system comprising:

a bulk transmitter optic;

an illumination source comprising a plurality of light emitters aligned to project discrete beams of light through the bulk transmitter optic into a field ahead of the optical system; and

a micro-optic channel array disposed between the illumination source and the bulk transmitter optic, the micro-optic channel array defining a plurality of micro-optic channels, each micro-optic channel including a micro-optic lens spaced apart from a light emitter from the plurality of light emitters with the micro-optic lens being configured to receive a light cone from the light emitter and generate a reduced-size spot image of the emitter at a focal point displaced from the emitter at a location between the emitter and the bulk transmitter optic; and

a light detection system comprising:

a bulk receiver optic configured to receive the discrete beams of light from the field; and

an optical assembly having a plurality of micro-optic receiver channels defining a plurality of discrete, non-overlapping fields of view in the field, the optical assembly comprising:

an aperture layer having a plurality of discrete apertures arranged along a focal plane of the bulk receiver optic;

an array of photosensors disposed behind the aperture layer; and

a plurality of lenses positioned between the aperture layer and the array of photosensors.

17. The optical system for performing distance measurements set forth in claim 16 wherein the bulk transmitter optic comprises one or more lenses configured as image space telecentric lens in which the discrete beams of light output from the illumination source through the micro-optic channel array are parallel to each other

18. An optical system for performing distance measurements, the optical system comprising:

a stationary housing having an optically transparent window; and

a light ranging device disposed within the housing, the light ranging device comprising an optical transmitter coupled to a platform, the optical transmitter comprising:

a bulk transmitter optic;

an illumination source comprising a plurality of light emitters aligned to project discrete beams of light through the bulk transmitter optic into a field ahead of the optical system; and

a micro-optic channel array disposed between the illumination source and the bulk transmitter optic, the micro-optic channel array defining a plurality of micro-optic channels, each micro-optic channel including a micro-optic lens spaced apart from a light emitter from the plurality of light emitters with the micro-optic lens being configured to receive a light cone from the light emitter and generate a reduced-size spot image of the emitter at a focal point displaced from the emitter at a location between the emitter and the bulk transmitter optic.

19. The optical system for performing distance measurements set forth in claim 18 wherein the light ranging device is a spinning light ranging device further comprising:

a motor disposed within the housing and operatively coupled to spin the light ranging device including the platform and optical transmitter within the housing;

a system controller disposed within the housing, the system controller configured to control the motor and to start and stop light detection operations of the light ranging device.

20. The optical system for performing distance measurements set forth in claim 18 wherein the bulk transmitter optic comprises one or more lenses configured as image space telecentric lens in which the discrete beams of light output from the illumination source through the micro-optic channel array are parallel to each other.