

論文 / 著書情報
Article / Book Information

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論文要旨

THESIS SUMMARY

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Department of, Graduate major in 電気電子 コース
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申請学位 (専攻分野)： 博士 (工学)
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要旨 (英文 800 語程度)

Thesis Summary (approx.800 English Words)

Beam scanning technology has been attracting much attention thanks to its application in 3D sensing such as structured-light sensing and LiDAR. Mechanical beam scanners were first demonstrated to meet the urgent requirement of scanning light sources. However, due to concerns about long-term stability in complex environments, scanning speed, large size, and high assembly cost, non-mechanical beam scanner scanners have been attracting much attention. One famous non-mechanical beam scanner could be designed based on optical phased array (OPA). However, large-scale, and dense integration of phase shifters for getting narrow far-field beam and higher resolution is a critical problem. The requirement of a high-power external light source and extra power consumption also precludes its application in consuming devices. Previously, we reported a one-dimensional (1D) solid-state beam scanner based on VCSEL waveguide/amplifier. It offers a narrow line beam with divergence of $<0.1^\circ$, small device size of $<0.05\text{mm}^2$ and high output power of $>3\text{W}$. However, its FoV of $<30^\circ$ has to be improved and the requirement of external light source limits its module size for application in mobile devices. Besides, developing 2D beam scanning is essential thanks to its significantly larger far-field power density than 1D fan-beam scanning.

In this thesis, a seed VCSEL will be integrated to the solitary 1D beam scanner for mm-scale packaging size. The 2D collimated-beam scanning will also be demonstrated by assisting with a cylindrical lens. The FoV and resolution for both 1D and 2D beam scanning will be greatly enhanced by DOE-based optics.

Firstly, the principle, fabrication process, and characteristics of beam scanner will be discussed. It was designed on a slow-light high-dispersion VCSEL waveguide/amplifier. The beam scanning could be realized by coupling light with tuning wavelength and the power of coupled light could be amplified to 3W by injecting current to the scanner above the threshold. In the experiment, a 6mm-long solitary beam scanner was designed and fabricated. By injecting light from external laser with wavelength tuning from 841nm to 844.5nm, the fan-beam 1D scanning with FoV of $>7^\circ$ and resolution of >308 . For smaller available packaging size by omitting the requirement of external light source, a high-power slow-light seed VCSEL was integrated to the solitary beam scanner. The seed VCSEL was formed by the same epi structure with scanner, on which a shallow-depth grating was etched to realize single-mode lasing. By increasing the current injected into the seed VCSEL, the thermally-induced redshift of lasing wavelength could be realized. Therefore, the output angle of beam scanner could be scanned with wavelength tuning of coupled light from seed VCSEL. It could realize the beam scanning range of $>7^\circ$ and resolution of ~ 100 by using a 2mm-long beam scanner.

Besides, a method of increasing the FoV and resolution of VCSEL beam scanner was proposed and demonstrated based on DOE-based optics and counter-propagation integration. The counter-propagation integration could make the scanner cover the symmetrical FoV and therefore enable to obtain double FoV. A 7-spot DOE could split the original beam into 7 beams with similar separation. By scanning the beam to fulfill the separation between 0th and 1st order, all the separation will be covered simultaneously and thus the FoV will be enhanced by 7 times. The resolution was also 7 times as large as that without DOE and reach >4000. Similarly, the same method could be used to enhance the FoV and resolution of a seed VCSEL integrated beam scanner. However, considering the output angle of beam scanner is farther away from vertical direction than solitary beam scanner, two prism mirrors were simply stacked to deflect the beam closer to vertical direction. The FoV and resolution could be enhanced to >108° and >1400, respectively. The longest side of total module including optics is as small as <10mm thanks to the omission of external light source.

A 2D beam scanning module with enhanced FoV and resolution will be proposed and demonstrated. The beam scanning in the ϕ direction could be realized by fabricating beam scanners array and assisting with cylindrical lens. In the θ direction, the beam scanning could be performed as the same function proposed previously. Instead of separated counter-propagation scanners, counter-propagation-switchable scanners array could be formed by sharing the beam scanner for smaller chip size. Also, a 2D DOE could be placed to obtain FoV enhancement in both ϕ direction and θ direction. The FFP of 2D beam scanning by using a 20-scanner array and 1D DOE and by using a 6-scanner array and 2D DOE were measured, which realized the FoV of $64^\circ \times 14^\circ$ and FoV of $70^\circ \times 45^\circ$ respectively. It is noted that although the FoV in ϕ direction could be enhanced by 2D DOE, the power penalty due to beam splitting will be more serious.

Real-time structured-light depth sensing was realized based on solid-state beam scanner integrated with a seed VCSEL. Rather than flash sensing, a scanning function gives an improved signal-to-noise ratio in outdoor applications for lower power consumption. In our experiment, a depth accuracy could stay at less than 300 μ m for 35 cm target distance with a low output power of smaller than 1mW even if sunlight shot noise is added to the system. It also shows great accuracy stability with lateral resolution points number increasing to 50,000 (100 \times 500) with a framerate of 20 fps.

The solitary beam scanner was fabricated and integrated to a seed VCSEL. The FoV of >100° was obtained by using the beam scanner and DOE-based optics. By using a 6mm-long solitary beam scanner, the record resolution of >4000 was obtained, and by using the seed-VCSEL-integrated beam scanner the total module size was optimized to mm scale. 2D beam scanning module was also proposed and demonstrated by using VCSEL beam scanner array, cylindrical lens, and DOE-based optics. The FoV of $70^\circ \times 45^\circ$ was realized with resolution of >30,000.

備考：論文要旨は、和文 2000 字と英文 300 語を 1 部ずつ提出するか、もしくは英文 800 語を 1 部提出してください。

Note : Thesis Summary should be submitted in either a copy of 2000 Japanese Characters and 300 Words (English) or 1copy of 800 Words (English).

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