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Image acquired by FMCW-LiDAR using Slow-light Photonic Crystal Modulator based on Si-Photonics Technology

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Abstract

Toward one-chip solid state LiDAR, Si-photonics-based slow-light photonic crystal (PhC) modulator was installed to LiDAR system with FMCW external electrical modulation method. The result proved the slow-light PhC modulator could be used in LiDAR system to acquire distance image. The investigation of power dependence are also discussed for higher image quality.

1. Introduction

For self-driving mobilities such as cars and drones, the Light Detection and Ranging (LiDAR) is being developed as one of techniques for ranging measurement and environmental scanning purpose. To install the LiDAR system for these applications, realization of compact and solid state systems is crucial. To achieve such purpose, we proposed to use Si-photonics technology with frequency modulated continuous wave (FMCW) operation and with photonic crystal (PhC) structure to enhance scanning angle from LiDAR antenna [1]. In previous report, we also proposed the technique of FMCW signal generation by electrical-domain wavelength scanning using an external lithium niobate (LN) modulator and an arbitrary waveform generator (AWG) and successfully verified that it was possible to captured the image with this method [2]. In this report, for the first time, The LN modulator is replaced by a slow-light PhC modulator chip and images are captured as one step toward full integration of LiDAR system on Si-photonic platform.

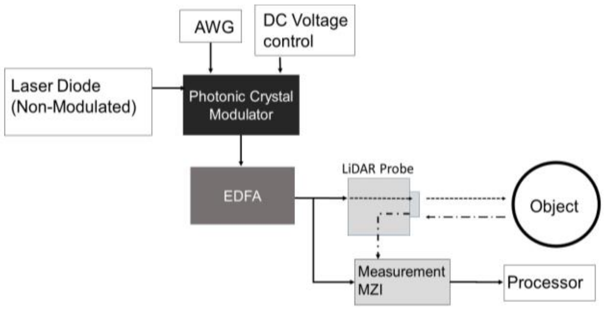


Fig.1 The system setup in the experiment

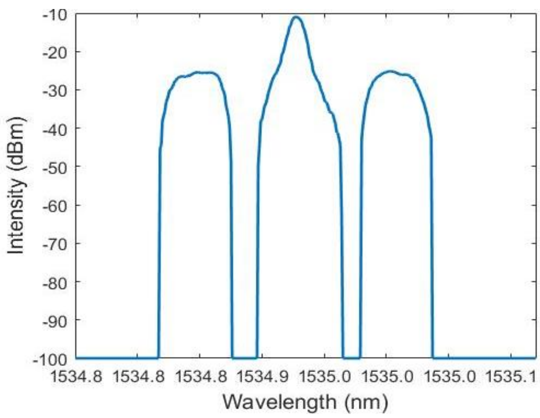


Fig. 2 The modulated optical spectrum after PhC modulator

2. System Setup

The overview of system setup is shown in Fig 1. A CW tunable laser without modulation was input to an PhC modulator. The PhC modulator was modulated by the frequency swept electrical signal generated by the AWG to generate frequency swept optical signal. The detailed structure of PhC modulator can be found in Ref. [3], [4]. The PhC modulator was fabricated in commercial foundry service on Si-Photonics platform. Slow down factor and electrical bandwidth were about 20 and 10 GHz, respectively. The wavelength and power of the tunable laser were set to be 1535 nm and 14 dBm, respectively. The operation wavelength mentioned above was determined due to the optimal point of optical bandwidth of the PhC modulator. The AWG applied the electrical sweep sawtooth signal from 8 to 13 GHz with the repetition rate of 200 kHz to the modulator. The PhC modulator consisted of a Mach-Zehnder Interferometer which superimposed the electrical sweep from AWG to the light signal. The modulated signal will result in a double side band spectrum as shown in Fig. 2. The PhC modulator was driven with a modulation voltage of 3 V_{p-p} push-pull driving. However, the carrier frequency is not well suppressed. It may be due to the insufficient modulation condition adjustment and should be solved in the future. An Erbium-doped fiber amplifier (EDFA) was installed to the system to increase the power of the signal to compensate fiber-to-chip coupling losses. The modulated signal was fed to the LiDAR probe with Galvano mirrors and measured an object 1.5 meters away. The image had the scanning angle of 10×10 degree and the resolution of 512×512 pixel. The reflected light was captured by the same probe and interfered with the reference signal divided from the original signal and the interfered signal was detected by a balanced-photo detector. Then, ranging image was calculated by PC through an AD-convertor and FFT processing.

3. Results and Discussion

The intensity image at a certain position was shown in Fig.3. Figure 3(a) shows the image of the object by conventional camera. Figures (b) and (c) show the images from the LN modulator as reference and PhC modulator, respectively and Fig.3 (d) shows a distance image by PhC modulator. When comparing the result from the previous LN modulator and the PhC modulator, the image in this experiment could also distinguish the object, but had some quality degradation in contrast level. We also tried to check the image quality with the sweeping frequency from 5 to 10 GHz. However, the result was similar.

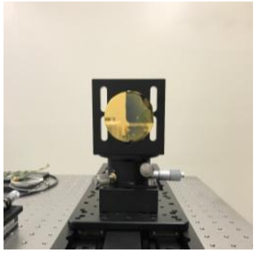
To investigate the reasons, the power dependent test was held. The powers at the output of the EDFA were set to be 10, 14, 16, and 19 dBm, which corresponds to the output power of the probe with 4.6, 7.4, 10.0 and 13.8 dBm, respectively. The images and summary were shown in Fig. 4 and Table I, respectively. For the LN modulator case, when the probe output power was 7.8 dBm, peak-to-noise ratio was > 20dB. Therefore, the image degradation was due to degradation of peak-to-noise ratio. One of the reasons is the peak spectrum was broadened, which most likely caused by multiple reflection in the system. The images improved as well as the peak-to-noise ratio. However, when the EDFA output reached the critical point, both peak level and noise floor level suddenly increased. Further investigation should be needed in near future.

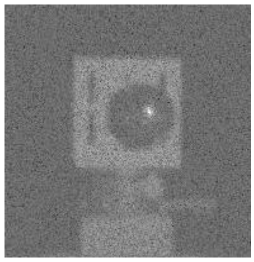
EDFA output (dBm)	LiDAR Output (dBm)	Noise Floor Level (dB)	Peak Level (dB)	Peak-to-Noise Ratio (dB)
10	4.6	7	13	6
14	7.4	8	15	7
16	10.0	9	20	11
19	13.8	34	52	18

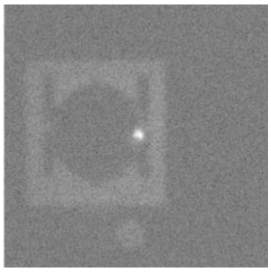
Table I Output power dependence

3. Conclusions

Distance image was successfully acquired by a slow-light photonic crystal modulator with FMCW external electrical modulation method. Compared with the system with lithium niobate modulator, peak-to-noise ratio was lower and this should be fixed toward compact one-chip LiDAR on Si-photonics platform.


(a) Photo image from camera


(b) LN modulator image


(c) PhC modulator image

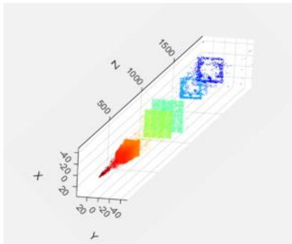
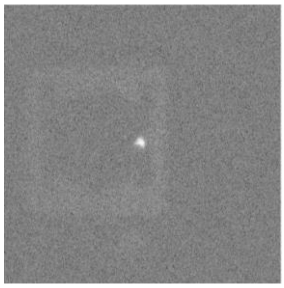
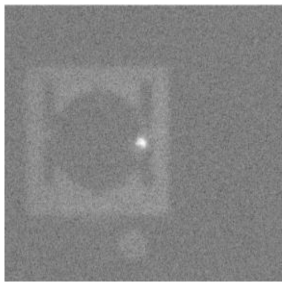
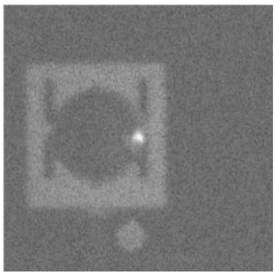

(d) Distance image

Fig. 3 Photo and acquired images by FMCW-LiDAR


EDFA output: 10 dBm


EDFA output: 14 dBm


EDFA output: 16 dBm

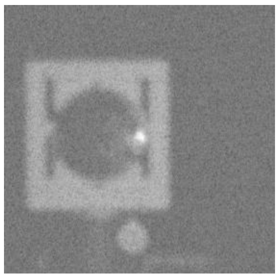

EDFA output: 19 dBm

Fig. 4 Captured Image with various output power

Acknowledgement

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References

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