Laser selective focusing utilized for remarkably enhancing the responses of photodetectors

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Abstract: Laser selective focusing structure has been introduced to enhance the response of the photodectectors remarkably. By using the amplitude Fresnel zone plate lens (FZPL) working in transmissive mode, high energy collection of laser light and high suppression of the other background light were obtained. A 36× gain and a 4× gain in responses were obtained for a mesa InGaAs/InP p-i-n photodetector and a planar InGaAs/InP avalanche photodetector(APD) integrated with FZPLs respectively, compared with the responses without FZPLs, when illuminated by the laser light. While illuminated by the Tungsten-halogen lamp, 30% deductions in responses were obtained with FZPLs compared with the responses without FZPLs. Strong enhancement of laser light absorption and obvious suppression of the light from the Tungsten-halogen lamp were obtained.

Key words: laser selective focusing; Fresnel zone plate; photodetectors

CLC number: TN21 Document code: A Article ID: 1007-2276(2014)05-1416-05

激光选择聚焦的响应增强型光电探测器

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摘 要:介绍了一种利用激光选择聚焦的结构来增强光电探测器的光电响应的方法。通过采用工作在传输模式的振幅型菲涅耳波带片,获得了较高的激光收集效率,同时也较好地抑制了背景光。当激光入射时,集成了菲涅耳波带片的 InGaAs/InP p-i-n 光电探测器和 InGaAs/InP 雪崩光电二极管的响应分别增强了 36 倍和 4 倍,而当模拟自然光的卤钨灯照射时,集成了菲涅耳波带片的两类光电探测器的响应均被抑制了 30%。集成了菲涅耳波带片的探测器显现出对激光信号的较强吸收, 对模拟自然光的卤钨灯光源的明显抑制。

关键词:激光选择聚焦; 菲涅耳波带片; 光电探测器

收稿日期:2013-09-17; **修订日期**:2013-10-20

基金项目:中国科学院战略性先导科技专项 B 类(XDB01010200);上海市科委项目(11nm0502100,11dz2283100,12nm0502900,12DZ2293600);国家基础研究重大项目(2011CB925600)

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0 Introduction

Laser detection system plays an important role in laser ranging [1], laser communication [2], laser tracking and Radar[3]. Due to the long distance and the atmospheric turbulence, the returned laser signals are always very weak when they reach the receivers. The presence of stray light makes it more difficult to detect the weak laser signals drowned in the background noise. So high sensitivity and high signal to noise ratio are becoming more and more important to the receiving systems, which are limited by the background noise and the dark current of the detectors. The detector's dark current is usually reduced by decreasing the detector′ active area, which will also decrease the energy collection and result in a lower response. Optical lenses are usually used in the receiving system to focus the energy on the detector, which at the same time collect the background radiation. In order to suppress the background noise, ultra-narrow band-pass filters are often used, which usually introduce a deduction of the signal energy from 20% to 80%. At the same time, the received optics is generally complicated and expensive.

In this paper, we describe a Fresnel zone plate lens (FZPL) integrated infrared photodetector which can selectively absorb the laser light while suppressing the background light, resulting in high sensitivity and high signal to noise ratio. FZPLs, as practical energy collectors, have been used in the microwave, millimeter and infrared frequencies [4-7]. But in the early research, FZPLs are the only characteristic of the focusing property. In this paper, by using the FZPL, laser light with specific wavelength is selectively absorbed by the photodetector, while the other light illuminating on the photodetector is greatly suppressed. At the same time, the active area of the photodetector can be designed as small as possible to reduce the dark current, while still keeping a high enhancement of the optical response. Therefore, high sensitivity of the laser light signals and strong suppression of the background noise make the FZPLs integrated photodetectors an attractive choice for the laser detection system. The FZPLs can be written by use of optical lithography on the substrates or on the front sides of the photodetectors. For the prototype measurements presented in this paper, the FZPL was only patterned on a quartz plate and placed in front of the photodetector.

1 Fabrication

The FZPL was patterned on a quartz plate by use of optical lithography and gold of 100 nm was electron-beam evaporated over a 5 nm layer of chrome used as an adhesion layer. Ten-zone circular FZPL was fabricated(as shown in Fig.1), with a transmittance function:

$$t(r)=\begin{cases}1, & r_{2m}\leqslant r<r_{2m+1}\\ 0, & r_{2m+1}\leqslant r<r_{2m+2}\end{cases}$$

$$r_j=\sqrt{j}\,r_1, j=0,1,2,\cdots,2N+2$$

$$r_1=\sqrt{f\lambda}$$

where f is the focal length of the FZPL which is designed as 30.4 mm and the first circle diameter of the FZPL r_1 is 217 μm. The diameter of the FZPL is 1.94 mm, with a spatial resolution of about 30 μm. The working wavelength was intended to be at 1.55 μm. At this wavelength the quartz plate was transparent.

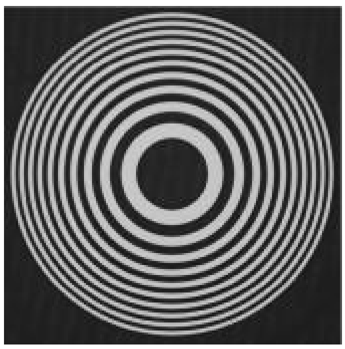

Fig.1 Electron-microscope photograph of the FZPL

Two types of photodetectors were used in this experiment. One was a mesa InGaAs/InP p-i-n photodetector with an active area of 50 μm $\times$50 μm, and the other was a planar InGaAs/InP avalanche photodetector(APD) with an active diameter of 60 μm. The two photodetectors were fabricated through normal post progress.

Smaller active areas of the photodetector can be designed to keep the dark current lower, which is guaranteed by the smaller spatial resolution of the FZPL with a narrower outmost zone width.

2 Experimental results and discussions

The test setup we used to characterize the FZPLs integrated photodetectors was depicted in Fig.2. Here, the FZPL patterned quartz plate was placed in front of the photodetector, which is convenient to be removed to test the responses of photodetectors without FZPLs. A CW laser diode emitting infrared radiation at 1.55 μm combined with a fiber collimator was used. Parallel light from the fiber collimator had a beam diameter of 6.6 mm. Newport 250 W Quartz Tungsten-halogen lamp was used to mimic the background light. Light from the laser diode or the Tungsten-halogen lamp came through the FZPL and illuminated on the photodetectors. The mesa InGaAs/InP p-i-n photodetector (photodetector A) was zero biased, and the planar InGaAs/InP APD(photodetector B) was 40 V reverse biased, working in a linear avalanche mode. The output powers of the laser diode were set as 0.5 mW and 0.1 mW for photodetector A and B respectively. Keithley 236 source measure unit was used to measure the responses of the photodetectors.

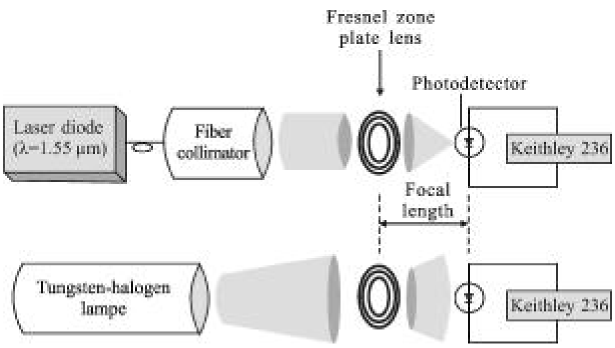

Fig.2 Schematic of the experimental setup to test the FZPL integrated photodetector's response

The FZPL integrated photodetectors were tested in the transmissive mode. In Tab.1 we presented the responses of the FZPLs integrated photodetectors and the photodetectors without FZPLs, in two types of illuminating conditions. When laser beam was illuminating, a 36× increase and a 4× increase in responses were obtained for photodetector A and B integrated with FZPLs respectively, compared with the responses without FZPLs. While illuminated by the Tungsten-halogen lamp, 30% deductions in responses were obtained with FZPLs compared with the responses without FZPLs. Strong enhancement of laser light absorption and obvious suppression of the light from the Tungsten-halogen lamp were obtained. Here the gain of response for photodetector B is smaller than photodetector A because of the periphery absorption of the active area, when illuminated without the FZPL. And the response enhancements are not as large as the theoretical values, which may be caused by the oblique incidence geometry and the attenuation of the quartz plate that in some extent also contribute to the deduction of the responses for the Tungsten-halogen lamp. If a reversed FZPL is used, which means the center circle is dark, larger deduction in responses of the Tungsten-halogen lamp would be realized and higher signal to noise ratios would be gotten.

Tab.1 Experimental responses of the photodetectors with FZPLs and without FZPLs on different incidences

Light source	Response			
	Mesa InGaAs/InP p-i-n		Planar InGaAs/InP APD	
	With FZPL	Without	With FZPL	Without
Laser	3.625	0.106	2.8	0.65
Tungsten-halogen lamp	0.44	0.63	10	15

In the following context, we will describe in details how the FZPL integrated photodetector works. When light is vertically incident upon the FZPL, the light passing through the transparent zones will have an optical path difference of $n\lambda$ and hence will interfere constructively in the focus point. As we all know, interference effects only occur between the coherent light, and only the light with a coherent length larger than the FZPL's diameter is able to interfere constructively in the focus point and has an energy convergence here. For the laser light, which is definitely coherent light, because of the narrow spectral width, the coherent length is commonly larger than one meter, which is much larger than the diameter of the FZPL. Accordingly laser light through the FZPL can interfere constructively in the focus point where the photodetector is located. While for the other light which is not coherent light, such as light from the Tungsten-halogen lamp, the coherent length is always in the magnitude of micrometer. So light from the transparent zones with a distance larger than the coherent length can't interfere and focus on the photodetector located in the focus point, resulting in a greatly weakened background light incidence. Therefore, for the photodetector located in the focus point of the FZPL, only the laser light with corresponding wavelength can focus on it, while the other light just passes through the FZPL and scatters away. So, by using a FZPL, laser light, which carries the signals, is significantly enhanced and the other background light is effectively suppressed, as well validated in the experiment.

But there is still a shortcoming about the integrated structure. Only the first diffraction order of the amplitude FZPL is used in the FZPL integrated photodetector, with a low diffraction efficiency of about 10%. The low diffraction efficiency has become the bottleneck that limits the application of FZPL. Many efforts have been made to increase the diffraction efficiency and remarkable improvements have been received, such as using the phase Fresnel plate zone and the multilevel Fresnel plate zone [8-10], which could be used to substitute for the normal FZPLs and integrate with the photodetectors to get higher enhancements of optical responses.

3 Conclusions

The use of FZPL to improve the response and suppress the background noise of an infrared photodetector has been demonstrated. Due to the interference, only laser light through the FZPL can interfere constructively in the focus point and hence can be absorbed by the photodetector located in this point, while the other light through the FZPL can be effectively suppressed. Experimental values of the gains in responses were 36× and 4× for the FZPL integrated mesa InGaAs/InP p-i-n photodetector and the FZPL integrated planar InGaAs/InP APD respectively, when illuminated by the laser light. Obvious 30% deductions in responses were obtained with FZPLs compared with the responses without FZPLs, when illuminated by the Tungsten-halogen lamp.

In summary, the FZPLs integrated photodetectors not only satisfy the requirement of large collection areas in space, but also provide the high sensitivities and high signal to noise ratios, which are valuable for the laser detection system.

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