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The Non-Uniform Characteristics Of A Photodiode

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Abstract: Silicon photodiodes are semiconductor devices responsive to high energy particles and photons. Photodiodes are widely used in applications such as light intensity measurements, photography, optical position sensors, laser range finders, optical communications, and medical imaging instruments. The non-uniform characteristic of the photodiode do not affect these applications in a considerable way. In this paper, an experimental study on the non-uniformity characteristics of photodiodes is performed using a laser source.

Keywords: photodiode, responsivity, non-uniformity, linearity

I. INTRODUCTION

Photodetectors convert a light signal to an electrical signal such as a voltage or current. This is typically achieved by the creation of free electron hole pairs (EHPs) by the absorption of photons. The photodiode is normally reversed biased. The applied reverse voltage results in a field E in the depletion region. This field separates the EHPs and drifts them in opposite directions. Drifting carriers generate a current, called photocurrent I_{ph}, in the external circuit that provides the electrical signal. The measured photocurrent I_{ph} in the external circuit is due to the flow of electrons per second to the terminals of the photodiode. Number of electrons collected per second is I_{ph}/e. If Po is the incident optical power then the number of photons arriving per second is Po/hν.

II. OPTICAL CHARACTERISTICS OF A PHOTODIODE

Photodiodes are semiconductor light sensors that generate a current or voltage when the p-n junction in the semiconductor is illuminated by light. Performance of a photodetector depends upon a number of parameters such as responsivity, spectral response, radiometric sensitivity, quantum efficiency, noise current, sensitivity and response time including the uniformity of the photodetector.

A. Quantum Efficiency

Quantum efficiency is defined as the fraction of the incident photons that contribute to photocurrent. The Quantum efficiency (QE) η of the detector can be defined as

$$\eta = \frac{I_{ph}/e}{P_0/h\nu} \qquad \textbf{(1)}$$

B. Spectral Responsivity

The responsivity (R) of a silicon photodiode is a measure of the sensitivity to light, and it is defined as the ratio of the photocurrent I_{ph} to the incident light power P_0 at a given wavelength.

Responsivity, $R = I_{ph}/P_0$ (2)

In other words, it is a measure of the effectiveness of the conversion of the light power into electrical current .

From (1) and (2) it is clear that,

$$R = \frac{\eta e}{h\nu} = \frac{\eta e \lambda}{h\nu}$$

The responsivity therefore depends on the wavelength. R is also called the spectral responsivity. Responsivity increases slightly with applied reverse bias due to improved charge collection efficiency in the photodiode.

C. Non-uniformity of a photodiode

A photodetector is defined to be uniform when the responsivity is constant over the surface, i.e., independent of the incident optical beam position on active area. Any change of responsivity over the surface is defined as non-uniformity. Non-uniformity is inversely proportional to spot size, i.e. larger non-uniformity for smaller spot size.

D. Linearity

A silicon photodiode is considered linear if the generated photocurrent increases linearly with the incident light power. Photocurrent linearity is determined by measuring the small change in photocurrent as a result of a small change in the incident light power as a function of total photocurrent or incident light power. Non-Linearity is the variation of the ratio of the change in photocurrent to the same change in light power, i.e. $\Delta I/\Delta P$. In another words, linearity exhibits the consistency of responsivity over a range of light power. Non-linearity of less than ±1% are specified over 6-9 decades for planar diffused photodiodes. The lower limit of the photocurrent linearity is determined by the noise current and the upper limit by the series resistance and the load resistance. As the photocurrent increases, first the non-linearity sets in, gradually increasing with increasing photocurrent, and finally at saturation level, the photocurrent remains constant with increasing incident light power. In general, the change in photocurrent generated for the same change in incident light power, is smaller at higher current levels, when the photodetector exhibits non-linearity. The linearity range can slightly be extended by applying a reverse bias to the photodiode. Photodetectors are normally operated in their linear region and the non-linear region is considered to be a disadvantage.

III. METHODOLOGY FOR THE MEASUREMENT OF NON-UNIFORMITY

A. Experimental set up

The experiment characterizes the photodetector as a device with repeatable non-uniformity. The repeatable non-uniformity of the photodetector forms the basis of this project work.The experiment was performed with 635 nm laser wavelength having 4.9 mW power output and the diameter of the laser beam was 1 mm. Silicon photodiode having active area of 100 mm^2 obtained from Edmund Optics, Singapore operating in photovoltaic mode is used.
The arrangement is shown in Fig 1.

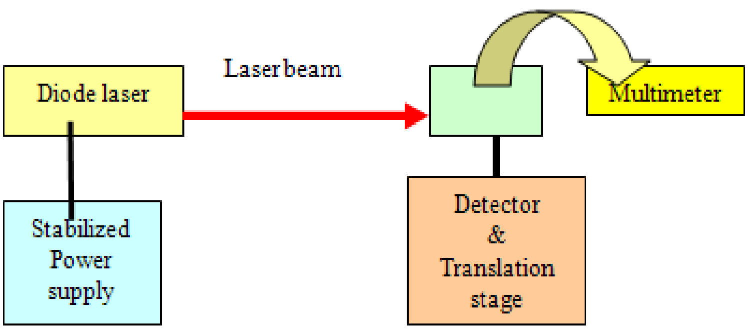

Fig: 1 Experimental set-up for measuring non-uniformity of photodetector

The silicon photodetector is scanned from left to right through the centre for various supply voltages to the diode laser source. The output voltages were observed using Digital multimeter. The readings were plotted and analyzed.

B. Experimental results

The plots of output voltage versus optical beam position for supply voltages 3V, 5V and 7V are shown in fig 2.

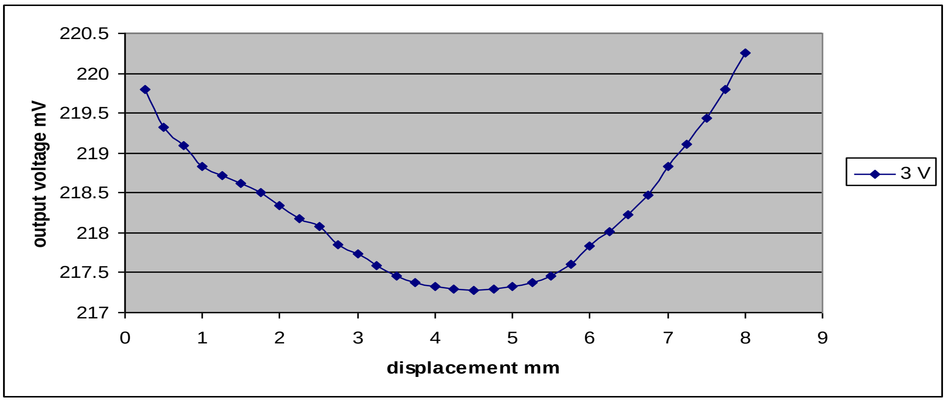

Fig 2. a) For 3 V

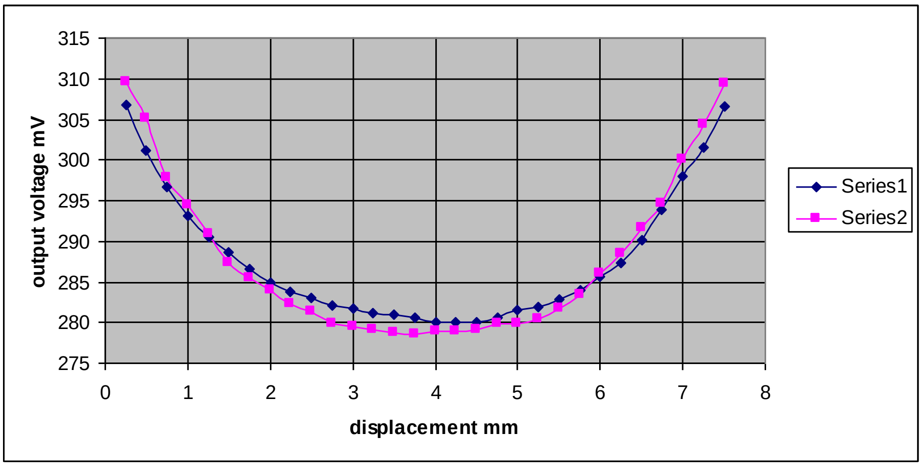

Fig 2. b) For 5 V

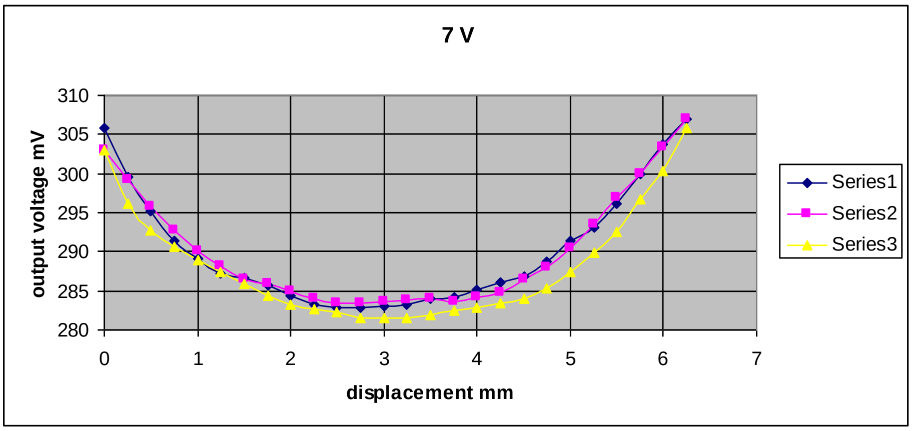

Fig 2. c) For 7 V

IV. DISCUSSIONS

An ideal photodiode should have a spatially uniform responsivity over the active area regardless of the position of the incoming beam. In other words if the spatial responsivity is uniform then regardless of the sensed location on the active area the same electrical output signal should be generated. But due to various effects, such as crystal structure of silicon, fabrication quality, radiation, heat, conduction and convection losses some spatial non-uniformity are observed. The experimental results shows this non-uniformity of the photodetector.

Theoretically, the homogeneity of the photodiode material itself can cause non-uniformity; therefore, for the same optical beam with same wavelength, the same radiant power coming to different parts of a photodetector, different output signals may be generated. The dependence of uniformity on photocurrent and on the diameter of the incident beam has been observed to vary from one photodiode type to another. The size of the active area has been shown to have an effect on the linearity of a photodiode. Thus it is understood that the photodetector shows non-uniformity which is repeatable. This was observed for the voltages 3 V, 5 V & 7 V. Though the focus of most applications is where the measurement of intensity is important, this project work has focused on the **non-uniformity** region. The **nonuniformity** characteristics of the photodiode can be explored for many application like vibration monitoring and analysis which involves measurement of both amplitude and frequency.

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