High-Speed Response Si PIN Photodetector Fabricated and Studied for Visible and Near Infrared Spectral Detection

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Abstract

In the present work, PIN photodetector has been fabricated by vacuum evaporation technique, Al was evaporated on top side of an intrinsic - type silicon and In was evaporated on down side and doped for each sides of an intrinsic silicon with thermal diffusion technique using a furnace system, in this method PIN photodetector is made.

The optoelectronic and electrical properties of photodetector were studied, PIN has spectral responsivity in visible and near infrared region and has peak responsivity at wavelength 900nm, I-V characteristic under dark condition the ideality factor is 3.2 and built-in-potential was determined by extrapolation of the curve (1/C^3) to a point 1/C^3=0 equal 0.8v. a high speed response for the photodetector was determined, it is equal less than 2.35nS.

Keyward: photodetector, vacuum evaporation, thermal diffusion.

Introduction

PIN photodetectors are widely used in optoelectronic circuits. In multiple applications such as high speed receivers, optical modulators, and solar energy collectors are used. Yet another application of PIN photodetectors is their used in optically controlled optical gates (OCOGs) that can be utilized for ultrafast optoelectronic optical switching, time division demultiplexing, or wavelength conversion in wavelength-division-multiplexed (WDM) transmission systems. [1],[2]

Often it is critical to understand the response of PIN detectors to large signal optical inputs. For example, large-optical signal response behavior is important in analog devices such as analog-to-digital converters. Photodetector large-signal response depends on how the voltage change due to photogenerated charge separation rises and relaxes. There are two primary voltage relaxation processes: a global effect, voltage decay through the external circuitry, and a local effect, voltage diffusion—also referred to as diffusive conduction. The voltage change due to the carrier separation in the top diode is represented by an identical opposite voltage change in the reverse-bias bottom diode. Both diodes have their reverse bias voltages reduced locally by equal amounts. [3],[4]

The response in this type of photodetector is, by design, strongly dependent on the local voltage decay.
behavior. These types of devices have a photo-absorption layer that converts input light into carriers such as electrons and holes. For an ultra wide-band response, the carrier-transit time in the photo-absorption layer should be much shorter than the required system response. The 3-dB-down electrical bandwidth limited by the carrier transit time is related to the carrier-transit distance. This structure permits the bandwidth and efficiency to be specified almost independently because the internal efficiency is determined not by the photo-absorption layer thickness, but by the photoabsorption length. Also it has the advantage to form the array structure because of its vertical arrangement compared with the difficulties rising from the horizontal structures of normal edge-illuminated devices.[4][5].

The aim of the present work the PIN photodetector is to make evaporation technique and thermal diffusion technique, which is the simplest and low cost technique, the optoelectronic and electrical properties were investigated.

**Experimental**

Silicon, cubic shape, intrinsic-type, have thickness 150µm with (111) orientation and high resistivity (1000Ω.cm) are used in this study, two faces top and down sides are polished to the mirror-like surface. Prior to deposition of two metal Al and In up and down sides respectively, these bulks are chemically etched in dilute hydrofluoric acid to remove a native oxides. Subsequently, after oxide removing the bulks washed with running deionized water, a high pure Al are made thin film with thickness 20nm are prepared by thermal evaporation of top side of silicon within a vacuum of the order 10⁻⁵ torr by balzer coating system after removed from the vacuum chamber, the silicon are doped with accepter impurities to make p-type by thermal diffusion in vacuum tube quartz at temperature 850°C at time 40min by furnace system. In same the method above n-type by In deposition with thickness 20nm in down side of silicon is made, but thermal diffusion at temperature 600°C. Ohmic contact was made by depositing Al and In film onto p-type and n-type respectively, in same method above. Fig(1) show diagram of PIN photodetector.

The Spectral responsivity measurements of PIN detector are made using monochromatic (MODEL746) in the range 400-1100nm .I-V measurements are done under dark conditions the measurements were carried out at (300k) and Dc power supply was used to bias the detector. The illumination was achieved by He-Ne and diode(550nm) laser fixed at power 1mW.

**Results and Discussion**

Fig.(2) represents the spectral responivity curve of PIN photodetector biased at 0.5v the spectral response shows the effect between 500 and 1100nm, it means that visible and near infrared region of spectral. The maximum responsivity was around 900nm this result approach silicon intrinsic.[11].

Fig.(3) represents the relative quantum efficiency of PIN as function of wavelength, two peak Q.E. was observed at 650 and 900nm. Fig. (4) shows I-V characteristics of PIN detector the outline of the reverse bias voltage curve exhibits very small leakage current the rectification factor about 7.2 at 1v and no breakdown found at 2v, on the other hand the forward current varies approximately exponential with apply voltage it is obey the tunneling-recombination at a high voltage bias, the ideality factor n is 3.2 calculated by the following eq. [6].

\[
n = \frac{q}{KT} \cdot \frac{\partial V}{\partial \ln(I/I_s)} \quad \ldots \ldots (1)
\]

Where q/KT is reciprocal of the volt equivalent of temperature, I_f is forward current and I_s saturation current density, it is equal 10µA. To shows fig. (5) photo current response of the detector for two laser He-Ne and diode have power 1mW as a function of bias voltage the fig. shows maximum response of the laser at bias between 1 to
1.4v the photocurrent have about 800 to 1000 µA, the laser He-Ne is more responsivity than laser diode. From Fig. (6) shows change of a capacitance as a function of reverse bias. The decreasing of capacitance value with increasing reverse bias voltage was observed due to increasing depletion layer area with increasing reverse bias. [7] The cubic of a capacitance as function of reverse bias, the linearity characteristics of this plot confirms that the junction is graded type as shown in Fig.(7), the built-in voltage was determined by extrapolation of the curve C-V plot where C-3=0 and was found about to be 0.8v.[8], it is agree with Ref.[9].

FIG (9) shows raise time of PIN detector, the detector increases the speed response with the increase of applied reverse voltage due to the strong electrical field separation charge hole and electron [10]. We calculated the raise time from eq.[11]

\[ Tr = 2.2RC \]  \( \text{Where } R=50\Omega, \text{ } Tr=2.3\text{nS} \]

Conclusion

The obvious result and discussion, conclude that:

1- The PIN photodetector is detected in visible and near infrared region.
2- The Peak spectral responsivity is at wavelength 900nm.
3- The PIN can be used as solar cells.
4- High Q.E. at wavelength 900nm.
5- High speed sensitive to light in period at 2.35ns depends on bias voltage.

Reference

[5] Ibrahim Kimukin, Necmi Biyikli, Bayram Butun, , Orhan Aytur, , Selim M. Ünlü, "InGaAs-Based High-Performance p-i-n Photodiodes " IEEE PHOTONICS TECHNOLOGY LETTERS, VOL. 14, NO. 3, MARCH 2002
Fig. (1) show diagram of PIN photodetector

Fig. (2) Spectral Response of PIN Photodetector
Fig. (3) Relative Quantum Efficiency of PIN as function of Wavelength

Fig. (4) I-V Characteristics of PIN Photodetector
Fig. (5) Spectral Response of detector for two laser He-Ne and diode have power 1mW as function of bias voltage.

Fig. (6) C as a function of reverse bias.
Fig. (7) $C^3$ as function of reverse bias voltage.

Fig. (8) Raise time detector as function of bias voltage.