Indigenous Development of Silicon PIN Photodiodes Using a 4" Integrated Circuit Processing Facility

Anita Topkar, Arvind Singh, Bharti Aggarwal and C.K. Pithawa
Electronics Division
and
A.S. Rawat
Laser & Plasma Technology Division

Abstract

A wide range of single element silicon PIN photodiodes and 16-element PIN photodiode linear arrays have been indigenously developed using the 4" integrated circuit processing facility of Bharat Electronics Limited, Bangalore. The photodiodes show low dark currents and good optical performance in the visible range. The overview of this technology development activity is presented in this article.

Introduction

Silicon PIN photodiodes feature high speed, low series resistance, low dark current and low junction capacitance resulting in low noise and fast response time of the order of a few ns. Compared to photomultiplier tubes, silicon photodiodes offer specific advantages such as low operating voltage (<100V), high quantum efficiency, insensitivity to magnetic fields, and small sizes. As a result, PIN photodiodes are now being used extensively in wide range of applications involving radiation monitoring, nuclear physics (for medium-energy charged particle detection) and particle physics experiments (electromagnetic calorimeters). These devices are widely used in laser based metrology applications (measurements of diameter, surface roughness, projectile velocity, distance and vibration) and beam parameter measurements (power, temporal profile, pulse energy). As scintillation detectors, major applications of PIN photodiodes are in the arena of security systems such as X-ray baggage scanning and cargo scanning, industrial tomography and medical imaging systems. The technology for the production of PIN photodiodes for the above mentioned applications was not available in our country resulting in dependency upon the foreign commercial suppliers for these devices. Therefore, indigenous development of these devices was taken up.

Fabrication Technology

Considering the range of applications of silicon photodiodes as mentioned above, indigenous technology development of silicon PIN photodiodes has been carried out using a 4" processing line of Bharat Electronics Limited (BEL), Bangalore. The silicon photodiodes have been fabricated using silicon IC fabrication technology. A planar process which combines oxide passivation with ion implantation gives
better device properties compared to diffused junction devices, and hence this process has been adopted for fabrication of the photodiodes. Oxide passivation over the surface is useful for reduction of leakage currents whereas ion implantation allows accurate control of junctions. N Type, <111>, 4-6 kΩ-cm high purity silicon wafers of 300μm thickness are used as starting material and the subsequent process steps have been optimized so that the generation of defects is minimized. The front P+ region has been obtained by boron ion implantation while phosphorous has been used to obtain a N+ region at the back. Several process steps have been incorporated to reduce the dark current. The breakdown voltage has been tuned to enable operation in full depletion mode so as to get a minimum terminal capacitance. Silicon dioxide has been used as an anti-reflection layer over the active region and it has been tuned for the wave length of CsI scintillator. Initially, process runs have been carried out using a test-mask to optimize the required electrical and optical performance. Subsequent to process development, another mask was designed to incorporate different types of photodiodes. This design incorporated photodiodes with sensitive area ranging from 0.5mm²-150mm², quadrant detectors and 16-element linear arrays of photodiodes. The main fabrication steps used for the fabrication of photodiodes are given below:

- Initial oxidation
- P+ lithography
- Screen oxidation
- P+ implant of boron
- P+ drive-in and anneal
- Back N+ implant of phosphorous, drive–in and anneal
- Contact opening, metallization and passivation on the front side
- Dicing and packaging

Subsequent to wafer fabrication, the photodiodes are packaged in different types of packages such as metal TO (Transistor Outline) packages with glass window or flat package using ceramic substrates. The packages were custom developed at BEL, Bangalore.

Fig.1 shows the photograph of fabricated wafer incorporating various types of photodiodes.

Performance of Photodiodes

The characterization of the photodiodes has been carried out by measuring the dark currents and reverse capacitance at different bias voltage using automated measurement setups. The typical dark currents at different bias voltages for a number of photodiodes of area 100mm² are shown in Fig. 2. The dark currents at voltages exceeding full depletion voltage are about 3-5nA/cm². The typical capacitance vs voltage characteristics for photodiode with area of 100mm² is as shown in Fig. 3. As can be seen, the capacitance at full depletion voltage is about 45 pF/cm².

Fig. 1: Fabricated wafer showing various types of PIN photodiodes
The optical characterization has been carried out by measuring the responsivity at different wavelengths of light in the visible range. The responsivity has been measured at 543nm, 632nm and 940nm wavelengths using laser/LED. During these measurements, the optical power of incident light on the photodiode was measured using a power meter. The current generated due the incident photons in the photodiode was measured using a transimpedance amplifier. The diodes were used in photoconductive mode and the output voltage was measured to calculate the photocurrent.

The optical response of the photodiodes was compared with commercially available photodiodes of similar specifications. The spatial uniformity of the optical response and linearity at different input optical powers was also measured.

The optical performance of the photodiodes has been observed to be as good as that of imported commercial photodiodes (Fig.4).

The spectroscopic performance of indigenously developed CsI-photodiode detector assembly for different gamma energies was investigated by coupling the photodiode to CsI scintillator. The CsI scintillator was grown at TPD, BARC. A CsI scintillator with dimensions of 10x10x15 mm³ was coupled to a photodiode of 10mmx10mm geometry for carrying out these measurements. Fig. 5 shows the response of CsI:PIN photodiode detector assembly for different gamma-ray energies over a range of 511keV to 1275keV [1].

The CsI-photodiode detector shows a good linearity in the 511 keV -1275 keV range. The detector shows energy resolution of about 16% at energy of 662 keV.
Types of Photodiodes Developed

Various types of photodiodes which have been developed include single element diodes, quadrant detectors and 16-element linear arrays. Some of these photodiodes are shown below:

- PIN photodiode with active area of 0.2 mm² (0.5mm dia.) and with a mini-lense window
- PIN photodiode with active area of 0.78 mm² (1mm dia.) and with a mini-lense window
- Quadrant detector with each element of 1.3mm x 1.3mm, 0.1mm gap and with a glass window
- PIN photodiode with active area of 25 mm² and with a glass window

Summary

Various types of PIN photodiodes have been indigenously developed using the 4” integrated processing facility of BEL, Bangalore and their performance has been evaluated. The photodiodes have been observed to have
performance comparable to that of commercial photodiodes. As this technology development was carried out using the foundry facility of BEL, the photodiodes will be commercially available from BEL, Bangalore. Using the technology developed, it would be also possible to tune the specifications such as geometry, types of segmentation, spectral response, etc., for specific applications.

Acknowledgement

The authors would like to thank Mr. G.P. Srivastava, Director E&IG, Dr L. M. Gantayet, Director, BTDG, Mr. R.K Patil, Associate Director (C), E&IG and Dr A.K. Das, Head, L&PTD for their support in carrying out this work. The contribution of Dr S.C. Gadkari, TPD and Mr. S.G. Singh, TPD, BARC in investigating the gamma response of CsI-photodiode detector is acknowledged.

References