process enables us to produce special kind of structure, like T-shaped FET's gates, diffraction gratings or computer generated holograms.

Short biography note

Lech DOBRZAŃSKI was born in Starachowice, Poland, in 1951. He received MSc degree from Warsaw Technical University in 1974. From 1974 to 1988 he worked in Scientific & Production Center CEMI. He was involved as a leader of the technological team in a project of LEDs on GaAsP (from 1974 to 1979). The successful set up of production line was awarded in 1978. From 1980 to 1985 he was involved in a project of polish microprocessor chip. Project was completed in 1984 and awarded. From 1985 to 1988 he worked at CEMI as a designer of bipolar integrated circuits. In 1988 he joined ITME. Here he was involved in organization of a laboratory for making semiconductor devices on $A_{III}B_V$. In 1994 he received PhD degree from ITME. His research interests include modelling of technology, modelling of semiconductor devices and ICs.

Andrzej KOWALIK was born in Lublin, Poland, in 1953. He received MSc degree from Warsaw University of Technology in 1978 and began work in Laboratory of Photomask in ITME. His research is concerned with electron beam lithography.

SILICON AVALANCHE PHOTODIODES DEVELOPED AT INSTITUTE OF ELECTRON TECHNOLOGY

Iwona Węgrzecka

The paper presents the design and properties of silicon epiplanar avalanche photodiodes developed and produced at Institute of Electron Technology (ITE). These photodiodes have got the excellent parameters for the detection of very fast and very weak infrared and visible radiation (especially for the wavelength range of 800 ÷ 900 nm).

Silicon avalanche photodiodes (APDs) are the most technologically advanced from a numerous family of optical detectors such as phototransistors, photocells, p - n photodiodes, and p - i - n photodiodes. Owing to the avalanche multiplication of optically generated carriers which takes place inside the diodes structure (in the avalanche region), APDs are characterised by high internal current gain. In the modern designs (based on the p - i - n structure) the separation and transport of the optically generated carriers proceeds very fast. Since the avalanche multiplication of the carriers is also a very rapid process, the APDs are the most sensitive and fastest photodetectors. The signal to noise ratio of APDs, in the real detection circuit, is the highest among the known photodetectors and NEP values (noise equivalent of power), conditioned by this ratio, are very low. These properties make APDs indispensable in the detection of very weak signals, they perform much better than p - i - n photodiodes attached to very fast and low-noise amplifiers.

With advanced design and technology of APDs very good detector of performances can be achived:

- high quantum efficiency η_λ (photoelectric sensitivity $S_{\lambda 0}$) for unit gain (for example $\eta_\lambda = 80\%$, $S_{\lambda 0} = 0.5$ A/W at $\lambda = 850$ nm, M = 1),
- short rise time (a few nanoseconds),
- low operating voltage (less than 300 V),
- low dark current at given operating voltage (a few nanoampers),
- high gain at given low noise current ($M > 100$ at $I_N < 1 pA/Hz^{1/2}$),
- smooth voltage - gain characteristics.

Notice: The magnitudes of most of these parameters depend on the diameter of active surface area of the photodiodes.

At Institute of Electron Technology, a family of silicon avalanche photodiodes with an active diameter from 0.3 to 3 mm has been developed and produced. These photodiodes are optimised for the wavelength range of 800 ÷ 900 nm. They have got an n^+ - p - π - p^+ epiplanar structure with an n - type guard ring, a p - type channel stopper and an n^+ - p hyperabrupt junction of the avalanche region.

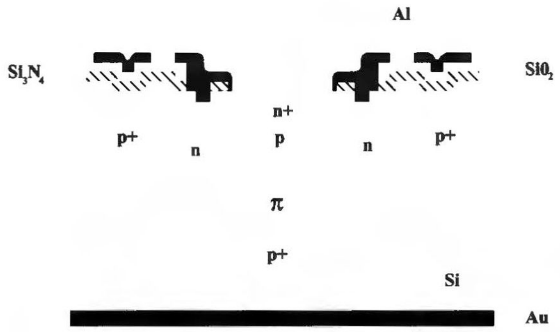

Fig. 1. Cross-section of the avalanche photodiode structure developed in ITE.

The schematic cross section of these photodiodes is shown in the Fig. 1. The initial material is a silicon wafer with a p - type epitaxial layer ($\rho_\pi = 200 \div 250\ \Omega$cm, $x_\pi = 30 \div 35\ \mu$m) grown on a p^+ - type, <111> orientated substrate. The n - type guard ring is provided by phosphorus pre-diffusion from $POCl_3$ source, followed by re-diffusion that takes place during thermal treatment of the active area ($N_S = 5\times10^{20}$ cm^{-3}, $x_j = 7\ \mu$m). The p - type channel stopper is made by implanting and then re-diffusing boron (re-diffusing is common for p^+ and p areas), $N_S > 10^{18}$cm^{-3}.

The photodiode active area (photosensitive, avalanche), covered with a 150 nm thick SiO_2 antireflection layer, constitutes the central area with the n^+ - p hyper-abrupt junction obtained by the arsenic diffusion from the amorphous silicon (doped with As during the deposition process) to the p - type region which was previously obtained by boron implantation and then boron re-diffusion.

The n^+ - p junction parameters for the designed APD structures, should attain values as follows:

- junction depth	$x_j \cong 0.4\ \mu$m,
- arsenic surface concentration	$N_S \cong 6\times10^{19}$ cm^{-3},
- boron surface concentration	optimum,
- p layer thickness	$x_p \cong 4.5\ \mu$m.

The photodiode structure is covered with a Si_3N_4 layer (~100 nm). An ohmic contact to the n - type region is made of aluminium and to the p - type substrate of gold.

A dopant distribution in an active region of APD is shown in Fig. 2. An optimal electric field distribution in a structure of APD at operating voltage is shown in Fig. 3.

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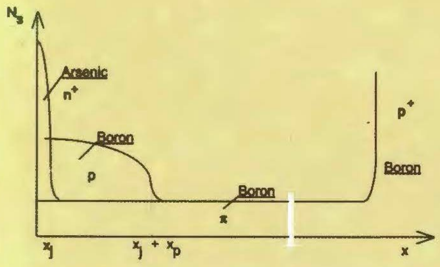

Fig. 2. Dopants distribution in active region of APD.

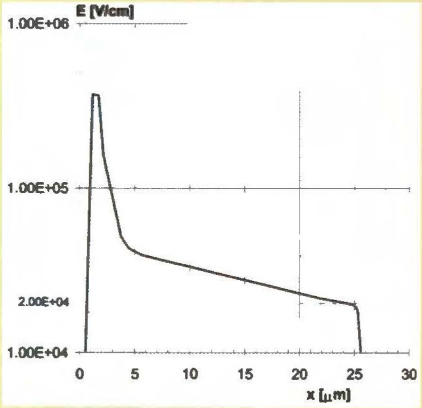

Fig. 3. Electric field distribution in active region of APD.

The APDs of the described design have got reach-through voltage of a p - region : U_{RT} = 48 ÷ 52 V and a typical operating voltage in the range 180 ÷ 220 V (the catalogue values 130 ÷ 280 V). A typical avalanche breakdown voltages of APD is usually about 10 V higher than its operating voltage.

The typical absolute spectral characteristic at the gain M = 1 is shown in Fig. 4. As the sensitivity of the photodiodes doesn't depend on their active area the diagram shown in this figure is valid for all the described types of diodes. An exemplary dependence of the gain (at λ=850 nm) and noise current (r.m.s. spectral noise current density) on the bias voltage for an APD with 0.3 mm diameters of photosensitive area are shown in Fig. 5. For this kind of photodiodes a noise current is very low (lower than 0.1 pA/Hz$^{1/2}$) at gains not higher than 100. For M>100 the M(V) dependence becomes sharper, the noise current begins to rise rapidly and at the gain of about 1000 it reaches the value of of 2 pA/Hz$^{1/2}$. Noise current versus voltage for all discussed diodes are shown in Fig. 6. To make comparison easier, the voltage axis was normalised to the avalanche breakdown voltage V_{BR}. This figure the vertical line operating points, which correspond connecting to the gain of M = 100 (at λ=850 nm) is marked.

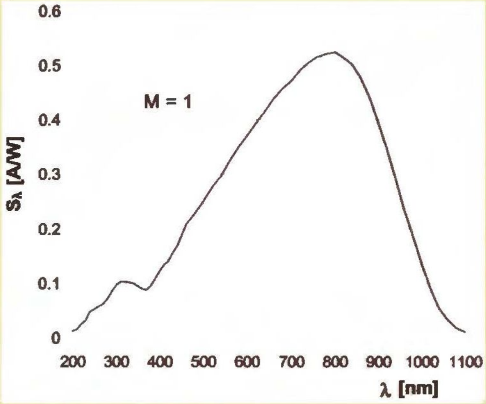

Fig. 4 Spectral response of APD (M = 1).

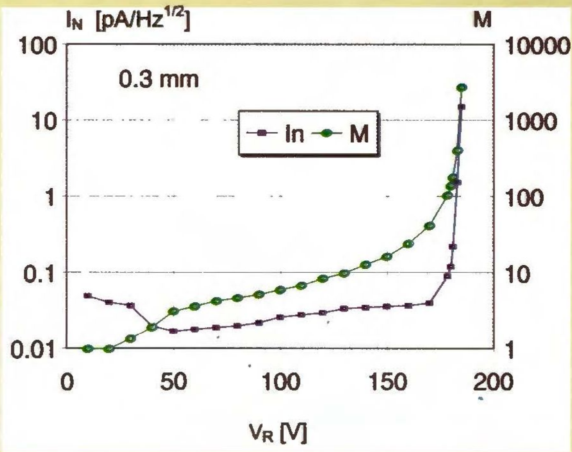

Fig. 5. Gain and noise current vs bias voltage of 0.3 mm APD.

Basic characteristics of APDs - gain , noise current intensity and dark current as a function of a bias voltage were measured using an automatic measurement set with a transimpedance amplifier.

Typical values of the basic parameters of the discussed APDs are listed in Table 1.

The APDs worked out and manufactured at ITE are characterised by the parameters at world-level. A considerable part of their production is assigned for foreign market.

At present, research is being conducted on a silicon avalanche photodiode with 5 mm-diameter photosensitive area, optimised for detection of scintillation radiation in ultraviolet and visible regions.

Table 1. Typical parameters of silicon avalanche photodiodes developed at ITE.

Parameter	Symbol	Units	BPYP 52 0.3 mm	BPYP 54 0.5 mm	BPYP 53 0.9 mm	BPYP 58 1.5 mm	BPYP 59 3 mm	Test conditions *)
Operating Voltage	V_R	V	180 ÷ 220 (min 130 ÷ max 280)					λ = 850 nm
Temperature Coefficient of V_R	α_{TR}	V/°C	0.75					
Sensitivity	S_λ	A/W	50					λ = 850 nm
Noise Current	I_N	pA/Hz$^{1/2}$	0.07	0.12	0.3	0.45	1.5	$P_\lambda = 0$
Noise Equivalent Power	NEP	fW/Hz$^{1/2}$	1.4	2.4	6	9	30	λ = 850 nm
Excess Noise Factor	F(M)		4					λ = 850 nm
Dark Current	I_0	nA	0.7	1.2	2.2	5	12	$P_\lambda = 0$
Capacitance	C_{tot}	pF	1.7	3	7	12	40	$P_\lambda = 0$
*) **Test conditions:** V_R for the gain M = 100; t_{amb} = 22°C								

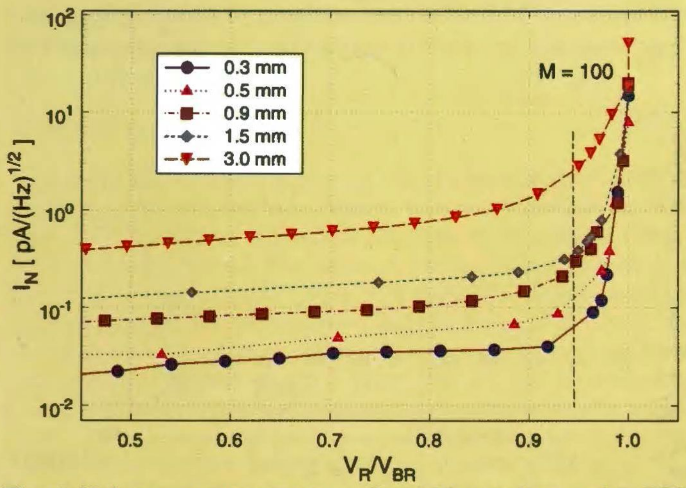

Fig. 6 Noise currents vs normalised bias voltage of 5 APD types.

ITE is ready to undertake studies on new kinds of silicon avalanche photodiodes for wide range of applications and offers the co-operation in design and production of devices with parameters suitable for specific needs.

I would like to thank all colleagues from ITE, especially M. Wegrzecki, T. Budzyński and S. Krzemiński and J. Bar for their contribution to APDs development and production.

Short biography note

Iwona WĘGRZECKA received the MSc degree in solid state electronics at the Department of Electronics, Warsaw University of Technology in 1967. Since 1967, she has been engaged at the Institute of Electron Technology (ITE) in Warsaw, working on design, technology and measurements of semiconductor photodetectors. She is an author and co-author of many semiconductor photodetectors. She has designed several types of silicon avalanche photodiodes. She has published a great number of scientific papers.

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MST Activities

THE 1997 JOINT INTERNATIONAL MEETING PARIS 1997
31th AUGUST - 5th SEPTEMBRE

The first ever joint meeting between the International Society of Electrochemistry and the Electrochemical Society was held in Paris on August 31st to September 5th the meeting consisted of 17 independent parallel symposiums with over 2500 participants.

Microsystems have been presented for many times in symposiums F1, M1 and P1a/b.

F1 symposium on Chemical and Biological Sensors and Analytical Electrochemical Methods described new trends in this area.

Microsystems technique was mentioned by J.R. Stetter and others from BCPS Department of Illinois Institute of Technology Chicago and University of Chicago in the paper titled „Micromechanical microfabrication of chemical sensors".

Very interesting ideas of Carbon - MEMS were presented by M. Madon and others from UC Berkeley and Lawrence National Laboratory in the article „Carbon Micromechining (C-MEMS)" An integrated silicon chromotographic column was presented by the team from the Technical University of Wrocław (see MST News Poland 1(5) March 1997).

M1 - Fifth International Symposium on Diamond Materials was mainly oriented toward basic research on deposition processes and material properties. Only few papers were devoted to microsystems - „Silicon and diamond for MEMS bearing applications in extreme environments" by M.N. Garalos from Hughes Aircraft Co and „Laser micromachining of diamond layers by V. Migulin and others from Korea Institute of Science and Technology .

For MEMS people the most interesting were session P 1a/b of two independent symposiums: the Fourth International Symposium on Semiconductor Wafer Bonding, and Eight International Symposium on Silicon on Insulator Technology and Devices.

On Monday September 1st two sessions of symposium P 1b with 8 papers presented were devoted to MEMS. New microsystem applications have been described and discussed for all days of this symposium. Unfortunately, proceedings of these symposiums will be available only in January 1998.

Poland was represented at the meeting in Paris by many scientists from different towns, universities and research centers.

For the first time it was clearly seem that scientific representants of Poland were treated seriously as future colleagues from military and economic alliances.

Jan A. Dziuban

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