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Double-Junction Photosensitive Devices with High UV Responsivity

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Conventional silicon photodetectors are sensitive within a spectral range from 400 to 1100 nm, approximately. There are, however, some applications (e.g. in medicine and space technology) requiring a broad banded response which extends into the UV region. The poor responsivity of silicon photodiodes at the low-wavelength end of the visible spectrum is due to the fact that high-energy photons are absorbed within a very shallow layer near the surface. Most of the electron-hole pairs generated in this manner are lost by surface recombination. Additional losses may arise from recombination at defect centers introduced during an impurity diffusion process. High UV sensitivity can be achieved with an extremely shallow p-n junction ($x_{j_1} \approx 0.1$ µm) and a low surface impurity concentration. A special diffusion process employing a partially masking SiO_2 layer is used to control the boron concentration profile accurately [1]. A second p-n junction with an appropriate depth ($x_{j_2} \approx 5$ µm) is necessary to collect electron-hole pairs generated by low-energy photons.

The basic design of a double-junction photodiode is shown in fig. 1a. Low-energy photons generate a photocurrent across the lower p-n junction which is created by vapor-phase epitaxy. Ultraviolet light is absorbed within the top p-layer. Both p-regions (substrate and diffused layer) are interconnected electrically by highly doped p-type stripes. The combined output (photocurrent vs. wavelength) is shown in fig. 2. The responsivity exhibits two maxima: a high-energy maximum at 400 nm and a low-energy maximum at 800 nm. It is obvious that the position of these maxima can be adjusted - within certain limits - by proper choice of the design parameters (especially x_{j_1} and x_{j_2}). Thus the spectral response of double-junction diodes can be tailored to meet requirements of specific applications.

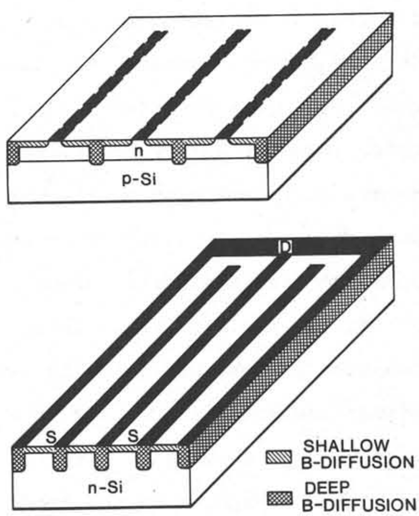

Fig. 1 Broad-banded photosensitive devices

a) Double-junction diode
b) Field-effect transistor

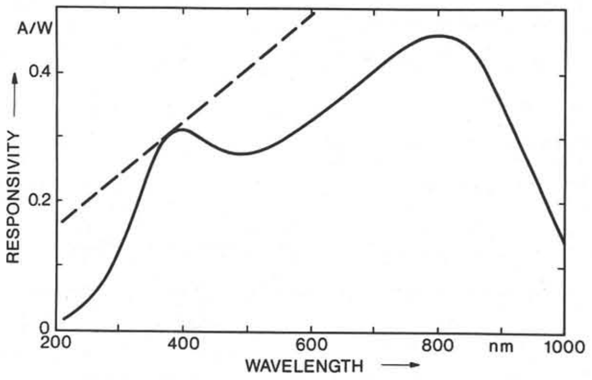

Fig. 2
Responsivity vs. wavelength of a double-junction photodiode.

The FET device shown in fig. 1b features a lateral sequence of shallow and deep p-n junctions. When the device is operated as a diode in the photovoltaic mode (source and drain short-circuited), a spectral response similar to that of a double-junction diode is obtained (fig. 3, curve 1). Operating the device in the photoconductive mode (source and gate short-circuited) yields a high gain ($\sim 10^4$) at the high-energy end of the spectrum (fig.3, curve 2). The gain decreases monotonically with increasing wavelength, since low energy photons are generating free carriers mainly within the bulk material; these carriers do not contribute to the conductivity modulation of the p-type channel.

The main disadvantage of the photoconductive mode of operation is the high dark current (amounting to 150 µA for the device shown in fig. 3). The dark current can be eliminated or considerably reduced when the gate is positively biased with respect to the source. An additional amplification mechanism is noticed, if a resistor is inserted into the gate circuit. The photocurrent generated at the p-n junction causes a voltage drop across the gate resistor, thus enhancing the drain current. This mechanism is most effective in the medium-wavelength range, i.e. for those photons which give rise to the highest response in the diode mode.

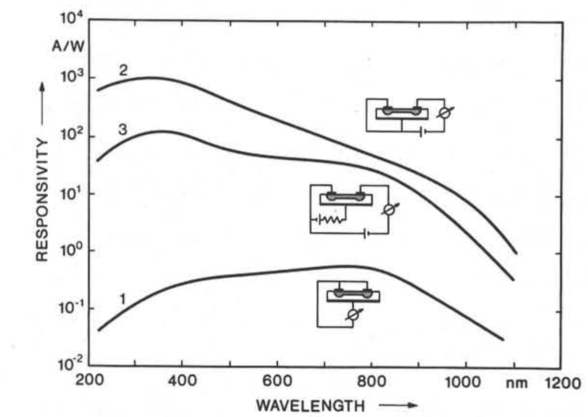

Fig. 3 Responsivity vs. wavelength of photosensitive FET devices

Curve 1: diode (photovoltaic) mode
Curve 2: photoconductive mode
Curve 3: FET mode (with U_{GS} = 1 V, R_G = 1 MΩ)

[1] W. v. Münch and C. Gessert, "Low surface concentration of boron in silicon by diffusion through silicon dioxide", *J. Electrochem. Soc.* 122 (1975), 1685.