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# PHOTO-RESPONSE SPECTRUM OF SURFACE BARRIER DIODES ON $GaAs_{1-x}P_x$ MIXED CRYSTALS *

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## ABSTRACT

Surface barrier diodes have been prepared by chemical deposition of thin gold film on samples of $GaAs_{1-x}P_x$ with x = 0.3. The spectrum of the photo-response over a spectral range covering the photo-injection from the metal and the intrinsic absorption regions of the semiconductor has been measured. From the photo-threshold corresponding to each region, the height of the energy barrier and the forbidden gap width of the semiconductor have been determined and are found to be 0.96 e.v. and 1.78 e.v. respectively for the investigated composition.

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## INTRODUCTION

The possibility of a wide variation of the basic properties of mixed crystals by changing their compositional structure is an important advantage of these materials. The change of band structure of the crystal considerably affects its optical and photo-electrical properties. Thus, devices sensitive to various ranges of electromagnetic spectrum can be prepared by changing the compositional structure of mixed crystals.

The most well studied and attractive till now are $GaAs_{1-x}P_x$ mixed crystals. Luminescent diodes with red radiations have already been industrially fabricated on their basis [1].

The conduction band minima of $GaAs_{1-x}P_x$ solid solutions have been studied [2] by measuring the spectrum of the photo-response of Schottky barriers on their basis. It was found [2] that the forbidden gap of $GaAs_{1-x}P_x$ remains a direct type for $x \leqslant 0.38$ which is in disagreement with the recent value $x \leqslant 0.46$. [3]

In the present work the spectrum of the photo-response of surface barriers on samples of $GaAs_{1-x}P_x$ with x = 0.3 is studied with the aim of measuring the forbidden gap width and the barrier height of this composition.

## EXPERIMENTAL

Surface barriers were prepared on n-type $GaAs_{0.7}P_{0.3}$ single crystals ($n \approx 10^{15}\ cm^{-3}$) grown by vapour phase epitaxy. Gold films were chemically deposited on the polished and etched surface of the crystals by the method described in Ref.4. Ohmic contacts to the semiconductor were achieved by using a laser technique [5].

The spectral distribution of the short circuit photo-current of the barriers is taken by illuminating the metal side using a light powerful diffraction grating monochromator type MDR-2 equipped with a 50-CPS chopping system and narrow band tuned amplifiers with synochronous detection followed by an automatic recording.

## RESULTS AND DISCUSSION

The photo-current per incident photon ($I_p$) was measured as a function of photon energy ($\hbar\omega$) of the incident monochromatic light. The spectrum is illustrated in Fig.1 and indicates that the response has two regions. The first region is where the photon energy is smaller than $E_g$ the energy gap of the semiconductor and the response is generally small. The photo-current in this region is due to the photo-emission of electrons from the metal into the semiconductor over the barrier. The second region (starting with a sharp increase), where the photon energy exceeds $E_g$ is a region where the response is some orders higher than the first. In this case the photo-current is due to the direct interband transitions ($\Gamma_{15}^{v} \rightarrow \Gamma_{1}^{c}$) of current carriers in the semi-conductor. Indeed the compositional structure of the samples used in this study (x = 0.3) has a direct band structure [2),3)], i.e. the absolute minimum of the conduction band and the top of the valence band are located in the same point (K = 0) of K space. Thus the direct optical transitions are allowed, by the wave vector selection rule, in the first order perturbation theory and the absorption coefficient has a sharp increasing edge starting at $\hbar\omega = E_g$. Since the photo-current increases by increasing the absorption coefficient, then the spectrum of the photo-current may also sharply increase at the beginning of the fundamental absorption as shown in Fig.1.

The spectral distribution of the short circuit photo-current may be useful in determining the metal semiconductor barrier height $\varphi_B$ and the forbidden gap width of the semiconductor. In the spectral region, where the response is due to the electrom emission from metal, the photo-current per incident photon as a function of the photon energy is given by the Fowler theory [6)]

$$I_p \sim \frac{T^2}{\sqrt{E_s - \hbar\omega}} \left[ \frac{Z^2}{2} + \frac{\pi^2}{6} - \left( e^{-z} - \frac{e^{-2z}}{4} + \frac{e^{-3z}}{9} \cdots \right) \right] ,$$

where $Z = (\hbar\omega - \varphi_B)/kT$, and $E_s$ is the sum of $\varphi_B$ and the Fermi energy measured from the bottom of the metal conduction band. Under the condition that $E_s >> \hbar\omega$ and $Z > 3$, the last equation reduces to

$$I_p \sim \frac{1}{2k^2 E_s^{1/3}} \left[ (\hbar\omega - \varphi_B)^2 + \frac{\pi^2}{3} k^2 T^2 \right] .$$

For $(\hbar\omega - \varphi_B) > \frac{\pi}{\sqrt{3}} kT \approx 3kT$, we get

$$I_p \sim \frac{1}{2k^2 E_s^{1/2}} (\hbar\omega - \varphi_B)^2 , \text{ or}$$

$$I_p \sim \frac{1}{k\sqrt{2E_s^{1/2}}} (\hbar\omega - \varphi_B) .$$



Thus on plotting $I_p^{1/2}$ again $\hbar\omega$ in the spectral region corresponding to the emission of electrons from metal, a straight line is obtained with a threshold energy equal to $\varphi_B$ as illustrated by the left line in Fig.2. The experimental value of $\varphi_B$ obtained from Fig.2 is 0.96 e.v. The abrupt increase in response at higher photon energy, that is represented by the right line in Fig.2, is due to the interband direct optical transitions in the semiconductor. The photo-threshold of this line may be taken as the forbidden energy gap $E_g$. [2)] The value of $E_g$ for the investigated composition (x = 0.3) is found to be equal to 1.78 e.v. which is in good agreement with the data of Ref.3.

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REFERENCES

1) A.A. Bergh and P.J. Dean, Proc. IEEE 60, 156 (1972).

2) W.G. Spitzer and C.A. Mead, Phys. Rev. A133, 872 (1964).

3) A.N. Pikhtin, Fizika i Tekh. Poluprov. 11, 425 (1977).

4) O.A. Omar, Egyptian Journal of Solids 2, 78 (1981).

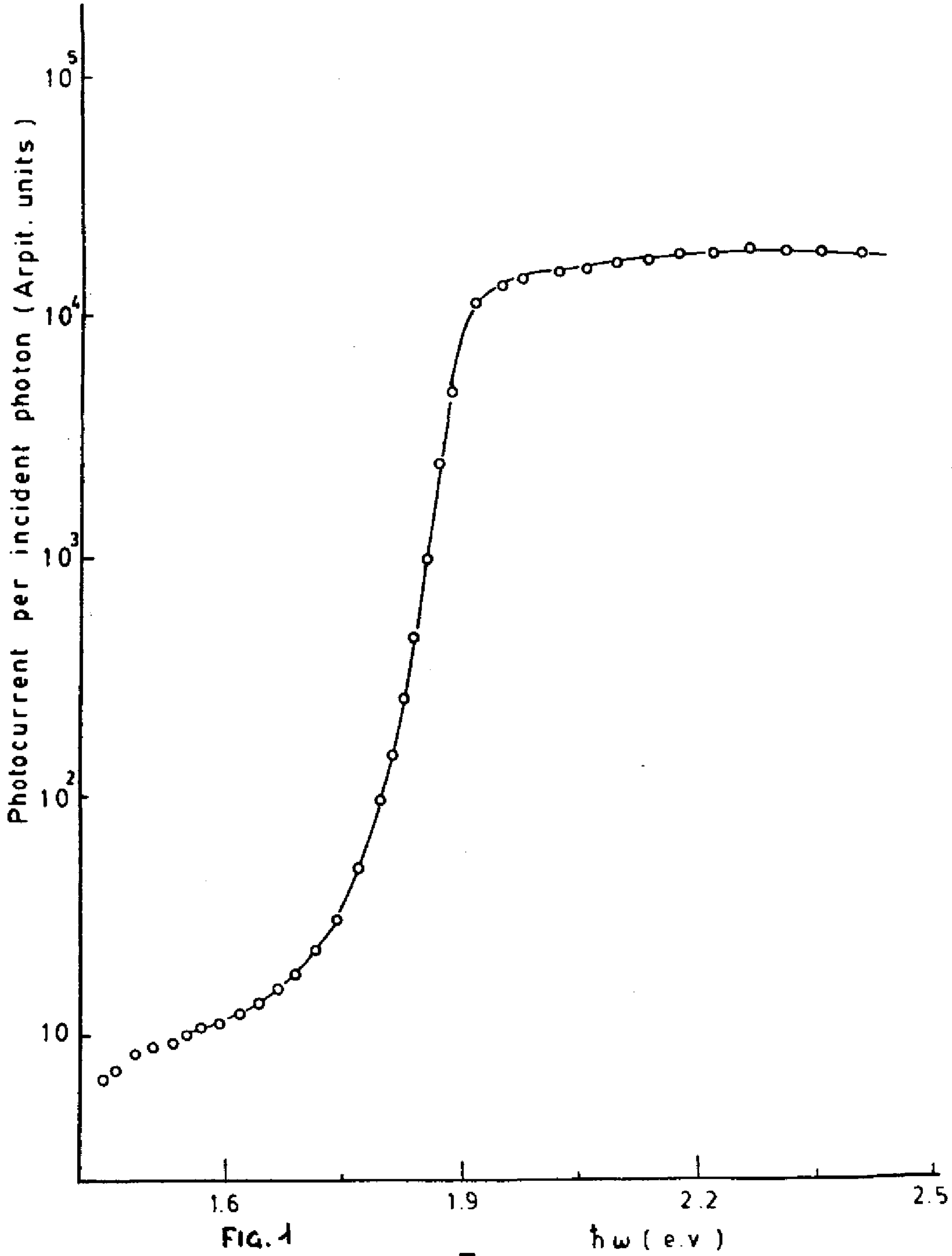
5) A.N. Pikhtin, V.A. Popov and D.A. Yaskov, Fizika i Tekhnika Poluprov. 3, 1646 (1969).

6) R.H. Fowler, Phys. Rev. 38, 45 (1931).

FIGURE CAPTIONS

Fig.1 Semilogarithmic plot of the photo-current against the photon energy ($\hbar\omega$) for surface barrier junction on n-type $GaAs_{0.7}P_{0.3}$ mixed crystal.

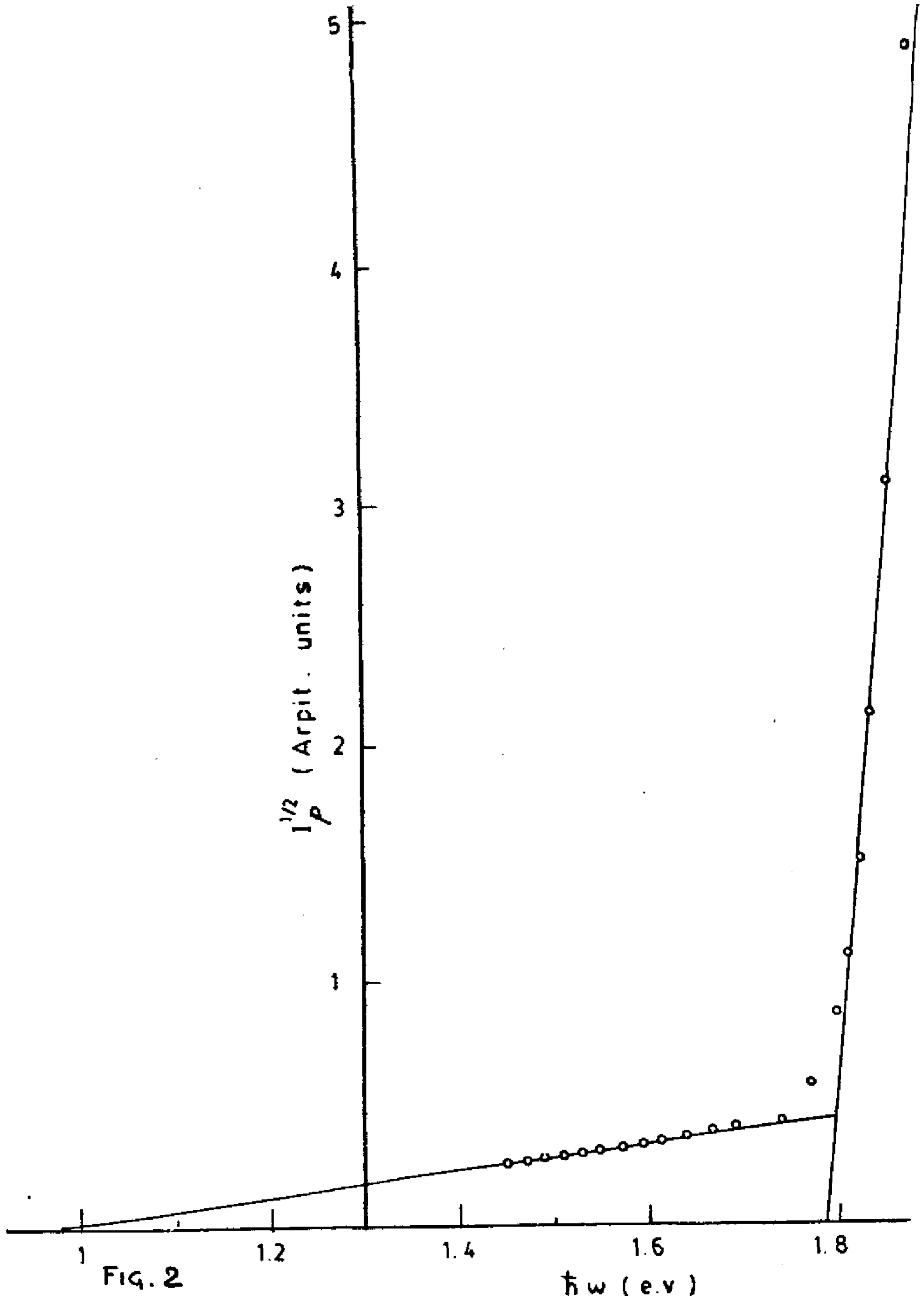
Fig.2 $(\text{Photo-current})^{1/2}$ versus photon energy for surface barrier on $GaAs_{0.7}P_{0.3}$.



Photocurrent per incident photon (Arpit. units)
10
10^2
10^3
10^4
10^5
1.6
1.9
2.2
2.5
ħω (e.v)


FIG. 1





$I_p^{1/2}$ (Arpit. units)
1
2
3
4
5
1
1.2
1.4
1.6
1.8
ħω (e.v)


FIG. 2

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