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To cite this article: Kiichi Kamimura *et al* 1980 *Jpn. J. Appl. Phys.* **19** L695

JAPANESE JOURNAL OF APPLIED PHYSICS
VOL. 19, NO. 11, NOVEMBER, 1980 pp. L695–L698

Properties of Schottky Barriers on p-Type Indium Phosphide

Kiichi KAMIMURA, Toshihide SUZUKI† and Akio KUNIOKA†

Department of Electronics, Tokyo Institute of Polytechnics, 1583 Iiyama, Atsugi, Kanagawa 243–02
†Department of Electric Engineering and Electronics, Aoyama Gakuin University, 6–16–1 Chitosedai, Setagaya-ku, Tokyo 157

(Received September 11, 1980)

Schottky contacts to the p-type InP have been fabricated and their electrical characteristics have been measured. The barrier height more than 0.8 eV are obtained with the contacts to the low work function metal such as Al, In, Sn and Sb. The barrier height is dependent upon the metal work function under the given metals. The surface state density is estimated to be 3.4×10^{12} cm^{-2} eV^{-1} from the barrier height versus the metal work function plot. The open circuit voltage and the energy conversion efficiency of the p-type InP Schottky barrier solar cell are 0.595 V and 8.2% under AM2 condition.

§1. Introduction

Indium phosphide (InP) has been the subject of extensive investigation on account of their wide spread application in microwave FETs,[1] IR lasers[2] and solar cells.[3] While the detailed physical and electrical properties of n-type InP Schottky diodes are well documented, comparatively little has been reported on the electrical properties of p-type InP Schottky contacts. Interest in p-type InP Schottky diodes stems from the observed rather high barrier height as compared to the n-type InP Schottky contacts.

Schottky barrier solar cells will occupy a major place among devices used in energy conversion systems, on account of the simplicity of fabrication and adaptability to polycrystalline thin film. GaAs MIS Schottky barrier solar cells have been shown to achieve an efficiency as high as 17%.[4] In this paper, p-type InP Schottky contacts were prepared and their electrical characteristics were measured and discussed. Photovoltaic cells were fabricated to show some promising device parameters as applied to a solar cell.

§2. Preparation

The Schottky diodes have been made by deposition of a metal film on (100) or (111) oriented p-type InP wafers with the carrier concentration of 5×10^{15}–1×10^{18} cm^{-3}. Before the gate metal deposition, the wafers were mechanically polished to a mirror like surface and etched with 1% bromine methanol. Immediately after the etching, the gate metal was deposited through a stainless steel mask. The metal was evapolated from a W spiral. The vacuum system was constructed with a conventional oil diffusion pump with a liquid N_2 trap. The ohmic contact to the back surface was formed before the etching by depositing Au/Zn (10 wt.%) and annealing at 450°C for 3 min. The shape of the Schottky electrode is a circural dot with diameter of 0.5 mm.

§3. Result and Discussion

3.1 *Barrier height*

The typical current-voltage curves of the Al/p-InP Schottky contact are shown in Fig. 1. The forward current density, as given by the diode theory, is

$$J=AT^2\exp\left(\frac{-q\phi_b}{kT}\right)\cdot\exp\left(\frac{qV}{nkT}\right), \quad (1)$$

where A is Richardson constant, ϕ_b the barrier height, n the ideality factor and others are their usual meanings. The ideality factor n is determined to be 1.61 from the forward curve in Fig. 1. The barrier height ϕ_b is estimated to be 0.90 eV from the reverse satulation current which is determined from the extrapolated value of the forward current to zero voltage, when A is assumed to be 84 A cm^{-2} K^{-1}. The forward current shows slight deviation from the exponential increase (straight line in Fig. 1)

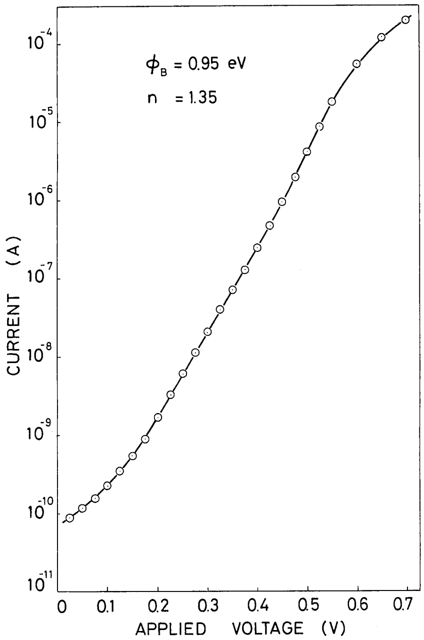

Fig. 1. Current-voltage characteristics of Al/p-InP Schottky diode.

near the zero voltage. This indicates the existence of some leakage current.

Figure 2 shows the typical capacitance-voltage characteristics of Al/p-InP Schottky diode (the same sample shown in Fig. 1). The diffusion potential V_d is determined from the intercept of the extrapolation at the voltage axis in Fig. 2. The value of the diffusion potential is 1.21 V and is farely large as compared to the value expected from the barrier height determined from the current-voltage curve in Fig. 1. The ellipsometric observation of the as-etched p-type InP surface showed the existence of a surface layer of 20–30 Å thick. A large value of the diffusion potential was observed also in GaAs MIS Schottky barrier solar cells. These may be explained by the positive or negative charges which exist in the interfacial layer between the gate metal and the semiconductor substrate.

One of the rather reliable methodes for the determination of the barrier height is the well known photoelectric measurement. The square root of the photoresponse per incident photon is plotted against the photon energy in Fig. 3. The light power was introduced to the barrier through the thin gate metal (Al in this case). The transmission of the gate metal was estimated by measuring the transmission of the Al film which was deposited simultaneously on a slide glass placed near the semiconductor substrate. The net photon numbers which reached the barrier were estimated from the transmission of the gate Al film and the power spectrum of the light source.

The barrier heights obtained by this technique are listed in Table I. The value obtained from the current-voltage measurement is closer to that obtained from photoelectric measurement and seems to be more reliable than that determined from the chapacitance-voltage characteristics. It is conceivable that the difference between the barrier height and the diffusion potential obtained from the capacitance-voltage characteristics is caused by that the value of the

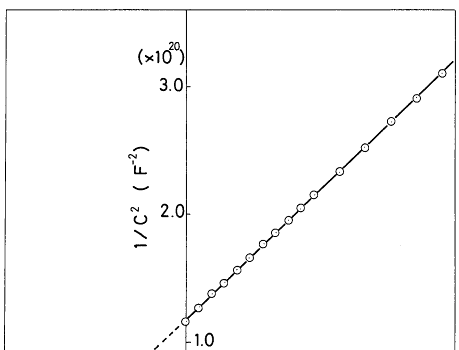

Fig. 2. $1/C^2$ versus applied voltage for Al/p-InP Schottky diode.

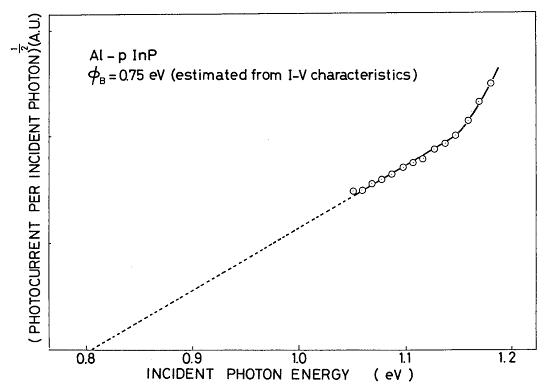

Fig. 3. Square root of the photoresponse per incident photon versus photon energy for Al/p-InP Schottky diode.

Table I. Barrier height determined from current-voltage, capacitance-voltage and photoelectric measurement.

Sample	Barrier height (eV)		
	I-V	*C-V*	Photo.
Al-1	0.75	—	0.81
Al-2	0.87	—	0.85
Al-3	0.89	1.16	0.89
Al-4	0.86	—	0.82
Al-5	0.90	1.39	—
Al-6	0.89	1.27	—

diffusion potential includes additional terms involving flat band voltage and oxide capacitance.

3.2 *Surface state density*

Figure 4 shows the relation between the metal work function ϕ_m and the barrier height ϕ_b which is determined from current-voltage characteristics. The barrier height shows fairly large dependence on the metal work function. This suggests that the surface state density is rather low at the p-type InP surface. For Schottky barriers on p-type semiconductors, the simplified form of the relation between the barrier height and the metal work function is given by[5)]

$$\phi_b=\gamma(E_g/q+\chi_s-\phi_m)+(1-\gamma)\phi_0, \qquad (2)$$

where E_g is the energy gap of the semiconductor, ϕ_0 the neutral level for surface states measured from the top of the valence band and χ the electron affinity of the semiconductor. The constant γ is defined by $\gamma=\varepsilon_i/(\varepsilon_i+q\delta D_s)$, where δ and ε_i are the thickness and the permitivity of the interfacial layer, respectively.

The straight line in Fig. 4 is well represented by the equation

$$\phi_b=-0.45\phi_m+2.76. \qquad (3)$$

For InP, χ_s is 4.40 eV,[6)] the permittivity ε_i is approximated by the free space value and the thickness δ is estimated to be 20 Å from the ellipsometric observation. The surface state density D_s and the neutral level for the surface states ϕ_0 were determined to be 3.4×10^{12} cm^{-2} eV^{-1} and 0.40 eV from eqs. (2) and (3), respectively. The surface state density at InP surface is much lower than that reported for GaAs Schottky contacts.[7)] The low surface state density was also reported for an InP MIS structure.[8)]

3.3 *Application*

Schottky barrier photodiodes were prepared with p-type InP to examine the device parameters for use as a solar cell. A serious problem in a Schottky barrier solar cell is the low open circuit voltage. Aluminum was used as the gate metal because of its low work function and low resistivity. The typical sheet resistance of the Al gate electrode was 65 ohm/□. The current-voltage characteristics were measured under solar illumination. Figure 5 shows the typical current voltage characteristics of the Al/p-InP Schottky barrier solar cell under AM2 condition. The open circuit voltage and the short circuit current were respectively 0.595 V and 12 mA/cm^2. The incident power density was measured by a Si solar cell which was calibrated by a thermo-pile. The energy conversion efficiency was estimated to be 8.5%. It may be possible to increase the energy conversion efficiency by forming the thin surface oxide

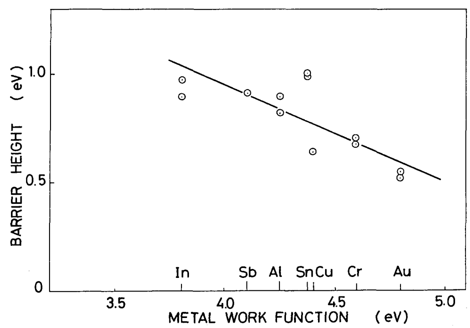

Fig. 4. Relation between metal work function and barrier height of p-InP Schottky contacts.

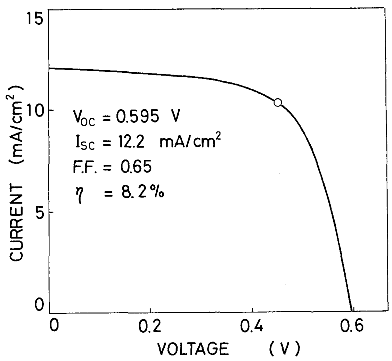

Fig. 5. Current-voltage characteristics under solar illumination (AM2).

layer and careful examination of the fabrication process; these are now under investigation.

§4. Conclusion

Schottky contacts to p-type InP were prepared and their electrical characteristics were measured. The high barrier Schottky contact was more easily fabricated on p-type InP than on n-type InP. The barrier height showed large dependence on the metal work function. The surface state density is estimated to be 3.4×10^{12} cm^{-2} eV^{-1} from the dependence of the barrier height on the metal work function. It may be possible to fabricate a high efficiency solar cell with p-type InP (MIS) Schottky contact.

Acknowledgement

The authors wish to thank Professor Y. Sakai of Aoyama Gakuin University for his encouragement and helpful discussions.

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