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Schottky contact of zinc on *p*-germanium

K K PATEL, K D PATEL and R SRIVASTAVA*
Physics Department, Sardar Patel University, Vallabh Vidyanagar 388 120, India

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Abstract. Metal–semiconductor contacts are drawing increasing attention due to their potential for applications in devices and integrated circuits. Experimentally, lower barrier heights have been reported more often for metallic contacts on *p*-type semiconductors. Here we report our results regarding barrier height of zinc on *p*-type germanium. The result is discussed in light of the mechanisms which could reduce the pinning effect in such contacts which are normally thought to be responsible for the observation of low barrier heights on *p*-type semiconductors.

Keywords. Schottky barrier height; M–S contacts; Fermi level pinning.

1. Introduction

Metal–semiconductor contacts (M–S contacts) exhibiting rectifying behaviour, usually referred to as Schottky contacts, have drawn substantial interest since their discovery by Braun (1874). In recent past, interest in tuning and trimming the Schottky barrier heights (SBH) have grown substantially because of their potential for applications, as sensors, fast switches, etc. Since each barrier results from band line up at the M–S interface, a clear understanding of the mechanisms governing it has been the objective of many investigations in the past (Sze 1993).

Whenever two materials come into contact, a realignment of the energy bands occurs at the interface to make the Fermi levels continuous throughout the material. Since the work functions of the materials in contact usually differ, a charge transfer is necessitated. In case of M–S contacts, such charge transfers result in the appearance of a charge depletion region on the semiconductor side only and that too for the cases where $\phi_m > \phi_{sn}$ or $\phi_m < \phi_{sp}$. Here ϕ_m represents the work function of the contacting metal and ϕ_{sn} and ϕ_{sp} represent the work functions of *n* and *p*-type semiconductors, respectively. However, the direct dependence of the SBHs on the metal work functions, as predicted by the above Mott–Schottky model, are normally not borne out in experiments. On the contrary, absence or weak dependence of the SBHs on metal work functions is normally observed and this is attributed to various factors like intrinsic surface states, metal-induced gap states, impurities, defects, microstructure, interfacial crystallography and orientations at the interface (Monch 1990; Tung 1992). Efforts for precise understanding about the role of the above factors is still being pursued with interest (Tung 1992).

Among the elemental semiconductors, Schottky contacts on germanium has not been investigated as much as on silicon. But now germanium is finding increasing applications in heterostructure microwave devices etc. Further zinc happens to be a soft metal capable of forming a variety of conducting alloys with metals like indium, tin etc.

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*Author for correspondence

Therefore, zinc contact on germanium appears to be interesting, specially for trimming and tuning of SBHs. In this paper we report our results on Schottky contacts on *p*-type germanium. It is found that such contacts are characterized by larger barrier heights of the order of the band gap of germanium.

2. Experimental

Germanium crystal having resistivity of ~ 10 ohm · cm was used in these investigations. Prior to the deposition of zinc, ohmic contact was made on the rough side of the crystal. For this purpose aluminium was evaporated and heated around 500°C for 30 min to form an aluminium-rich p^+ layer adjacent to this surface. The polished side of the crystal was etched in 4:1:3 solution (Sze 1988) of HNO_3, HF and CH_3COOH for 30 sec and then washed thoroughly with deionized water. The crystal was quickly dried and loaded with a suitable mask in the vacuum system. Zinc was evaporated in a vacuum of $< 10^{-5}$ torr at 150°C, to obtain diodes with an area of 0·017 cm^2. The current–voltage characteristics of these diodes were investigated with the help of Keithley electrometer model 614 and a DC millivolt source.

3. Results and discussion

The nature of observed *V–I* characteristics are shown in figure 1. It is observed that the diode exhibits good rectifying behaviour with low leakage current. Since the doping concentration is small ($5 \times 10^{14}/cm^3$) and the temperature of observations are not low

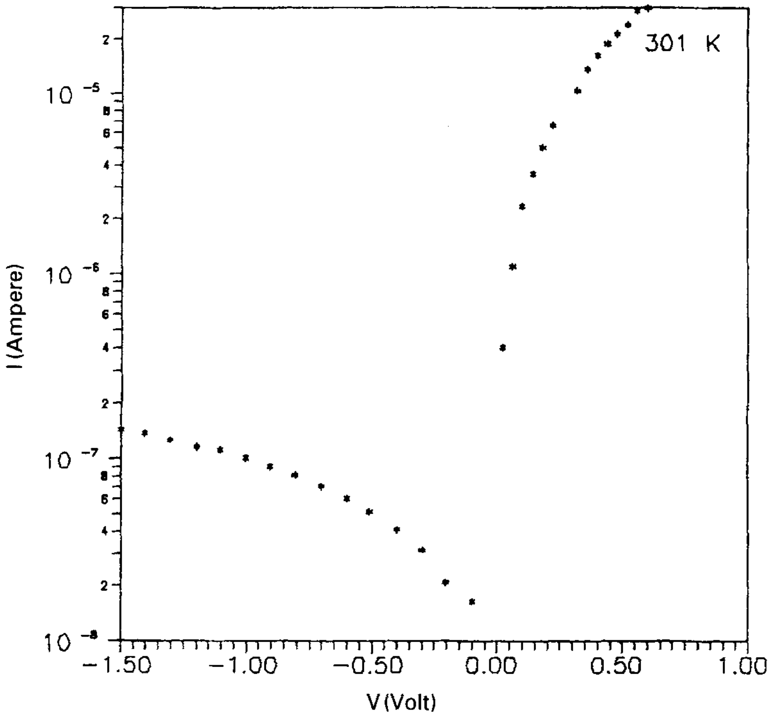

Figure 1. *V–I* characteristics of Zn–*p*Ge Schottky diode.

(301 K), the thermionic emission mechanism is expected to be the dominant mechanism of charge transport across the diode. Accordingly, the current–voltage characteristics should obey the relation

$$I = I_0 \exp[(qV/kT) - 1],$$

with saturation current I_0, given as

$$I_0 = AA^* T^2 \exp[-q\phi_b/kT].$$

Here A is the area of the diode, A^* the effective Richardson constant, ϕ_b the SBH, k the Boltzmann constant and T the temperature. To determine SBH, the leakage current I_0 was determined by plotting $\ln[I/1-\exp(qV/kT)]$ with V (figure 2). This method (Rhoderick 1988) was adopted since it has a distinct advantage over plotting the logarithmic variation of only forward current against forward voltage as it gives extended linearity even over reverse biases whereas it would otherwise have been limited only to small forward voltage ranges due to series resistance limitations (Roberto 1985). Further, it also takes care of the bias dependence of SBH (Rhoderick 1988). The value of SBH from above analysis is found to be 0·72 eV. The ideality factor as determined from the slope of figure 2 is found to be 1·08, which indicates that the diode under investigation is good. The SBH was also determined from the minimum of the Norde plot (Norde 1979) shown in figure 3. This also gives 0·70 eV as SBH of the Zn–*p*Ge contact.

The above value of SBH for Zn–pGe contact is interesting on two counts. Firstly, its magnitude is almost equal to the band gap of germanium. Secondly, it is contrary to the normal observation of comparatively lower SBHs for contacts on *p*-type than on *n*-type

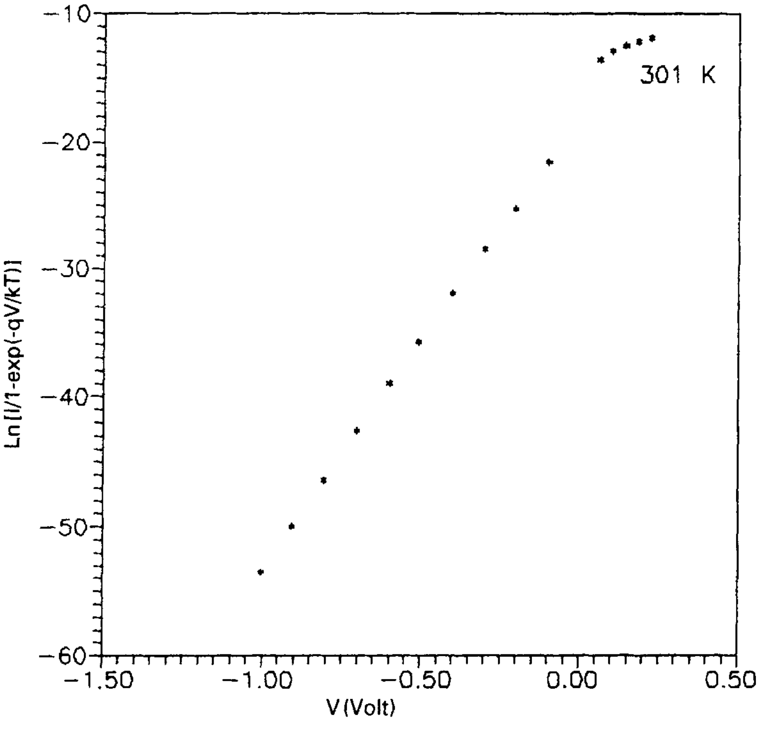

Figure 2. Ln $I/1-\exp(-qV/kT)$ vs V for Zn–*p*Ge Schottky diode.

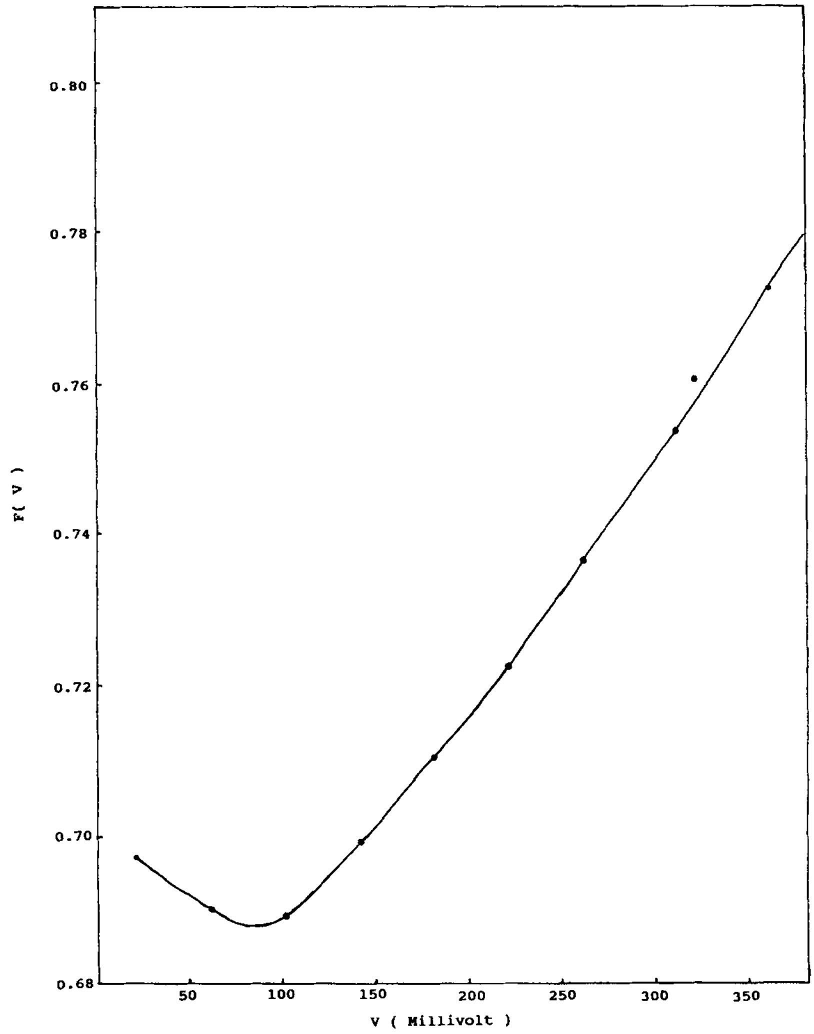

Figure 3. $F(V)$ vs V of Zn–Ge (p) Schottky at 301 K.

elemental semiconductors. However, comparatively lower SBHs for above type of contacts are expected to be observed where strong Fermi level pinning occurs and the charge transfer across the interface is controlled largely by charges in the interface states of the semiconductor. In such cases, SBHs on n and p-type semiconductors are almost equal to $(E_g - \phi_0)$ and ϕ_0 respectively. Here E_g is the semiconductor band gap and ϕ_0 represents the charge neutrality level for the interface states assumed to be uniformly distributed within the band gap. Since charge neutrality level of germanium is 0·18 eV referred to the top of the valence band (Tersoff 1984), SBH of same value is expected on the above model. However, the observed higher value of SBH indicates that mechanisms which tend to reduce the pinning effect on the Fermi level should be looked for.

Strong pinning at the charge neutrality level have been mostly observed in cases of contacts on clean and UHV-cleaved surfaces and have been found to be associated with low values of the slope parameter $\gamma (= d\phi_b/d\phi_m)$. On the other hand, Schottky contacts on chemically etched surfaces have been found to exhibit relatively higher values of SBH and hence the slope parameter (Werner and Rau 1994). Here it is notable that chemical etching, specially in HF-based etchants, have been found to result in passivation of interface states (Wittmer and Freeauf 1992). Reduced pinning effect has also been attributed to the shifting of some states near charge neutrality level towards the band edges (Schmidt *et al* 1988). Additionally, fluctuations in the charge neutrality level by presence of donor type defects (Spicer *et al* 1980) at the interface have also been invoked to account for higher SBHs in case of metal contact on *p*-type semiconductors.

Thus, present observations of near-band gap SBH for zinc contact on *p*-germanium might be resulting from a combination of effects which reduce Fermi level pinning at the interface. It may also be noted that the value the slope parameter expected for the present value of SBH on the basis of Cowley and Sze's (1965) linear model will be around 0·4, which is near the values of this parameter observed on chemically etched surfaces (Smith and Rhoderick 1971). It also indicates that an incomplete and partial pinning of the interface Fermi level is taking place in the presently investigated contact.

References

Braun F 1874 *Prog. Ann.* **153** 556
Cowley A M and Sze S M 1965 *J. Appl. Phys.* **36** 3212
Monch W 1990 *Rep. Progr. Phys.* **53** 221
Norde H 1979 *J. Appl. Phys.* **50** 5052
Rhoderick E H and Williams R H 1988 *Metal semiconductor contacts* (Oxford: Clarendon Press) p. 93
Roberto M Cibils and Buitrago R H 1985 *J. Appl. Phys.* **58** 1017
Schmidt M T, Podelsmik D V, Yu C F, Wu X, Osgold Jr. R H and Yang E S 1988 *J. Vac. Sci. Technol.* **B6** 1436
Smith B L and Rhoderick E H 1971 *Solid State Elect.* **14** 71
Spicer W E, Lindau I, Skeath P R and Su C Y 1980 *J. Vac. Sci. Technol.* **17** 1019
Sze S M 1988 *VLSI technology* (Singapore: Mc Graw Hill)
Sze S M 1993 *Physics of semiconductor devices* (New Delhi: Wiley Eastern)
Tersoff J 1984 *Phys. Rev. Lett.* **52** 465
Tung R T 1992 *Phys. Rev.* **B45** 13509
Werner J H and Rau U 1994 Springer Series in Electronics and Photonics **32** 89
Wittmer M and Freeauf J L 1992 *Phys. Rev. Lett.* **69** 18