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EFFECT OF UNIAXIAL STRESS ON InSb TUNNEL JUNCTIONS

C. W. FISCHER
Department of Physics, University of Guelph, Guelph, Ontario, Canada

and

E. L. HEASELL
Department of Electrical Engineering, University of Waterloo, Waterloo Ontario, Canada

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Abstract—The deformation potential constants of heavily doped InSb have been determined by applying uniaxial stress to *p–n* tunnel junctions formed below the surface of rectangular InSb bars. Stress applied parallel to the major axes of these bars and parallel to the junction plane resulted in a linear decrease in tunnel current as a function of stress. The percentage decreases were $24{\cdot}5\times10^{-3}$, $9{\cdot}5\times10^{-3}$ and $4{\cdot}5\times10^{-3}\,cm^2kg^{-1}$ for stress applied parallel to [010], [1$\bar{1}$0], and [111] directions respectively. The observed changes in tunnel currents are attributed to a decrease in the tunnel probability produced by a shift in the conduction band edge relative to that of the valence band. Our data is consistent with a hydrostatic deformation potential of -10 eV, and valence band deformation potentials $b=-1{\cdot}3$ eV and $d=-7{\cdot}4$ eV.

1. INTRODUCTION

Quantum mechanical tunneling between oppositely doped regions of a semiconductor diode has been used extensively to reveal various physical properties of the materials. For example, the general features of the energy gap have been studied via the electron–phonon interaction[1, 2] while the presence of defect or tailing states has been postulated to account for the excess current[3]. Hydrostatic pressure[4] and uniaxial stress have been used to alter the energy gap and hence to modify the barrier transmission probability. In Ge tunnel diodes, in the bias range where direct tunneling dominates Fritzsche and Tieman[5] observed that the change in tunnel current was proportional to the stress. Payne[6] has deduced the deformation potentials of Ge by relating the shift in the electron–phonon interaction energy, revealed by tunneling, to the applied stress. Long and Hulme[7] have used the theory developed by Pikus and Bir[8] to account for the observed change in tunnel current when [100] stress was applied to Ge tunnel diodes.

This paper deals with the effect of uniaxial stress on InSb tunnel junctions. Changes in the tunnel current as a function of stress are related to the change in energy gap through the compliance coefficients and the deformation potentials of the conduction and valence bands. Experimental techniques and results are presented and analyzed using Kanes[9] theory of tunneling and the theoretical results of Bir and Pikus[10].

2. EXPERIMENTAL

Specimens were prepared by diffusing Cd at 500°C for 60 hr into degenerate *n*-type ($N_d = 5\times10^{17}cm^{-3}$) bars (12 mm long × 2 mm wide × 1 mm thick) of InSb. The major axis of the bars were aligned within 1° of either the [111], [1$\bar{1}$0] or [010] directions with the normal to the 2 mm wide face lying in the [1$\bar{1}$0], [111] or [100] directions, respectively. A closed tube diffusion process was used, each ampoule containing three specimens, one of each orientation, and the diffusion source. The latter consisted of 100 μg of a 10 per cent solution of Cd in In. Diffusion in preference to alloying was used as the means to form the junctions for a number of reasons: Firstly, it is possible to produce similar junctions on any crystallographic plane, since the diffusion coefficient is independent of orientation whereas crystal regrowth, in the case of alloying, exhibits facets[16]. Secondly, metallic inclusions in the alloying process contribute to local stress inhomogeneity and this leads to anomalously high stress effects[7]. Finally, experiment indicates that it is difficult to achieve sufficient overcompensation using conventional alloying procedures[19].

Five junctions were formed below the surface of

the 2 mm wide face of each of the bars, by lapping the diffused surface until it coincided with the surface of shallow, flat bottomed pits which had been cut into this face before diffusion. Ohmic contacts were made to the diffused region using 1 ml dia. Au wire and In balls.

The junctions selected for this study showed little or no tunneling in the forward direction. The perfection of the junctions was assessed by studying the ratio of the reverse tunnel current in the presence of a longitudinal and transverse magnetic field. Junctions were discarded if the tunnel current was relatively insensitive to the magnetic field orientation even through it displayed an apparent normal $I-V$ characteristic. Measurements of the magnetic field dependence as a function of field strength, orientation, and reverse bias permitted determination of the tunnel exponential $\beta E_g^{3/2}$, and its bias dependence. The results of this method were compared with those obtained by matching Kane's tunneling expression to the reverse $I-V$ characteristic ($-10^4\text{A/cm}^2 < I < 0$). Both tests were applied to all junctions and only those yielding consistent values were used for stress studies. Further details of the methods and results are reported in Ref. [11].

Uniaxial compressive stress was applied to the specimen via a jig, lever and weight system similar to that described by Balshev[12]. The jig was composed of a fixed upper piston and a lower piston free to move in an accurately polished bore. Alignment of the major axis of the specimen with the axis of the jig was ensured by careful adjustment during the process of attaching brass cups to each end of the specimen. The assembly was then placed in the stressing jig and separate current and voltage leads were attached to each junction on the bar.

The stress dependence of the reverse current was studied since it is not complicated by the presence of excess and diffusion currents as is the forward current. Figure 1 illustrates a typical reverse $I-V$ characteristic with stress as a parameter. All junctions studied with stress parallel the [010] direction showed similar fractional decreases in current. Differing fractional changes were observed for stress in the $[1\bar{1}0]$ and [111] directions. The fractional reduction in current as a function of stress for the three orientations studied are summarised in Fig. 2. The stress dependence of the fractional reduction in tunnel current was independent of reverse current density in the range $0-10^3\text{A/cm}^2$. For convenience in the later analysis the data presented in Fig. 2, corresponds to a reverse bias of 50 mV and current densities of about 100A/cm^2.

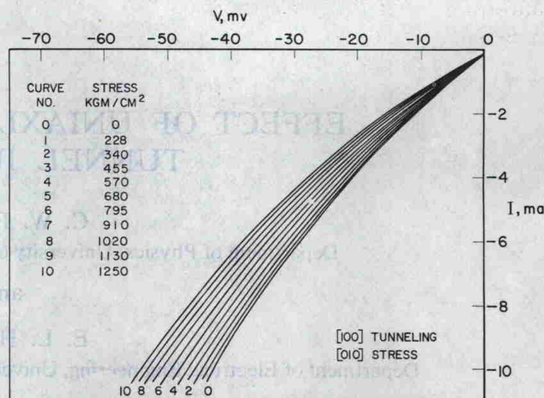

Fig. 1. Typical $I-V$ reverse characteristics with stress as a parameter.

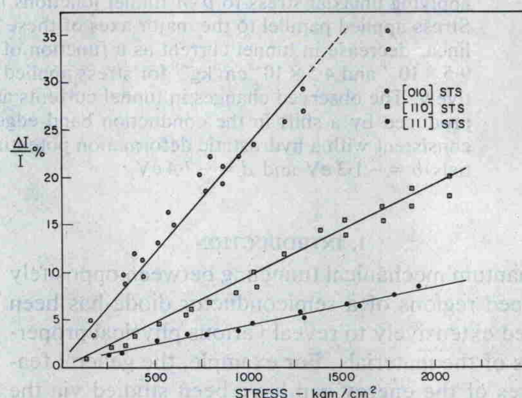

Fig. 2. Percentage change of reverse current at fixed bias as a function of stress for three stress orientation.

Sensitive dI/dV and d^2I/dV^2 studies performed at the same time failed to reveal any stress dependent fine structure that would correspond to the lifting of the Γ point degeneracy of the valence band. Studies at Helium (4.2°K) and nitrogen (77°K) temperatures were essentially identical. No evidence of Landau splitting was found for fields of up to 120 kG, and temperatures of 1·8–4·7°K.

The slope of the linear low stress region of the data of Fig. 2 gives percentage decreases in current of $24{\cdot}5 \times 10^{-3}\text{cm}^2/\text{kg}$ for $\chi \| [010]$, $9{\cdot}5 \times 10^{-3}\text{cm}^2/\text{kg}$ for $\chi \| [1\bar{1}0]$ and $4{\cdot}5 \times 10^{-3}\text{cm/kg}$ for $\chi \| [111]$. For stress greater than approximately 10^{+3}kg/cm^2 the slopes decrease slightly.

3. DISCUSSION

The reduction in tunnel current at fixed bias can be explained on the basis of a reduction in the tunnelling probability. For most purposes the tunnel current is adequately described by the two band,