Table (3-1). The valence band parameters given by experiments. (A, B, N) and $(D_u, D_{u'}, D_d{}^V)$ are given in units of $\hbar^2/2m_0$ and eV, respectively.

Group	$-A$	$-B$	$-N$	κ	D_u	$D_{u'}$	$D_d{}^V$
Dexter *et al.*[a]	13.1 ±0.4	8.3 ±0.6	32.1 ±0.5	3.9			
Levinger *et al.*[b]	13.27	8.63	33.6				
Goodman[c], Fletcher *et al.*[d]	13.21	8.56	33.36	3.9			
Okazaki[e], Hensel[f]	13.2	8.12	33.72	3.9			
Hensel[g]	13.38 ±0.02	8.60 ±0.04	34.08 ±0.12	3.60 ±0.04		3.91 ±0.25	
Otsuka *et al.*[h]					4.2 ±0.2	4.9 ±0.5	
Hall[i]					3.15	6.1 ±1.3	
Glass[j]					3.1 ±0.5	4.1 ±0.5	
Balslev[k]					2.7 ±0.5	3.2 ±0.4	
Present	13.50 ±0.05	8.80 ±0.09	35.20 ±0.23	3.9	3.14 ±0.20	4.00 ±0.20	$-5.2^{-0.5}_{+1.0}$ or $3.3^{+0.5}_{-1.0}$

a. R.N. Dexter, H.J. Zeiger and B. Lax: Ref. 1).
b. B.W. Levinger and F.R. Frankl: J. Phys. Chem. Solids **20** (1961) 281.
c. R.R. Goodman: Ref. 7).
d. R.C. Fletcher, W.A. Yager and F.R. Merritt: Ref. 6).
e. M. Okazaki: Ref. 9).
f. J.C. Hensel: Ref. 8).
g. J.C. Hensel: Ref. 14).
h. E. Otsuka, K. Murase and H. Fujiyasu: Ref. 13).
i. J.J. Hall: Ref. 25).
j. A.M. Glass: Canad. J. Phys. **43** (1965) 12.
k. I. Balslev: Phys. Rev. **143** (1966) 636.

mined very accurately from the first and second quantum lines, using Hasegawa's second order perturbation method which takes the spin-orbit split-off band into account. For determining κ, the above parameters and the assumption that $B-N/3\cong 0$ are used. Values of D_u and $D_{u'}$ obtained so far are to fall around 4 and 3 eV, respectively, except for Hall's data[25] for D_u (Table (3-1)). The values $D_{u'}=4.9$ and $D_u=4.2$ (eV) given by our previous experiments are a little larger than the present ones. In the past, a perpendicular squeezer ($H\perp\chi$) was used. The calibration of the stress was indeed accurate, but the subsequent analysis was difficult because of the poor resolution of the second quantum line.

Kohn[26] estimates the H_2 band parameter for Ge to fall in the range $0>H_2\geq -0.5$. The present result satisfies this requirement; namely $H_2=-0.41$. For D_u and $D_{u'}$ there exists a theoretical calculation by Goroff and Kleinman for Si.[27] No calculation has been available for Ge. One might see some significance in the ratio $D_{u'}/D_u$. According to Goroff and Kleinman, the ratio becomes 1.2 for Si. The present work for Ge gives $D_{u'}/D_u=1.3$, which is very close to the predicted value for Si.

3) Comparison of the value of D_d^V with those derivd by indirect method

The present work derives the D_d^V value solely from the same valence band cyclotron resonance measurement. One may, however, also find the quantity in an indirect way, which combines the hydrostatic compression data with the information of the conduction band deformation potential constants. In order to see how effective the latter method is, we shall give some qualitative discussions below.

The dependence of the band gap energy $E_g(L_1-\Gamma_{25}')$ on deformation is given by the relation

$$\mathrm{d}E_g/\mathrm{d}\ln V=\Xi_d+\Xi_u/3-D_d^V\ . \qquad (5.1)$$

The value of $\mathrm{d}E_g/\mathrm{d}\ln V$ has been measured by a number of workers. Experimental data prior to 1960 are summarized by Keyes and grouped into

two branches, the first branch centered around −3.8 eV while the second around −5.7 eV.[28] Recently Balslev adds another precise set of data.[29] As for the set of Ξ_u and Ξ_d, perhaps most reliable data are obtainable from cyclotron resonance experiments[18,30,31] and their values are given in Table (5-1). One can then derive the value of D_d^V from eq. (5.1) and the data in Table (5-1). The results are shown in Table (5-2). We get a considerable scatter of values for D_d^V from various possible combinations of the available data. Almost in every case, however, one finds D_d^V negative. One is thus inclined to choose the value −5.2 eV rather than +3.3 eV. The absolute value yet seems a little bit too large. Indeed the present method deduces the D_d^V value solely from the same experimental series of cyclotron resonance. But one should admit the large ambiguity inherent to D^2 which is difficult to overcome by experimental accuracy at present. The parameters in eq. (5.1) used to derive D_d^V, on the other hand, can be determined, in principle, as accurately as we wish. Especially the recent precise determination of Ξ_u and Ξ_d,[31] in the present authors' opinion, is quite encouraging for the use of eq. (5.1). A final conclusive value of $dE_g/d\ln V$ would then lead to a more realistic value of D_d^V than the one obtained in this work. More elaborate works both experimental and theoretical would be required to settle the problem.

Table (5-1). The deformation potential constants (Ξ_u and Ξ_d) as well as the energy shift of the conduction band.

Group	Ξ_u(eV)	Ξ_d(eV)	$\Xi_d+\Xi_u/3$ (eV)
Bagguley *et al.*[a]	16.6	−11.3	−5.8
Ito *et al.*[b]	18.7	−10.5	−4.3
Murase *et al.*[c]	19.3	−12.3	−5.9

[a]. Ref. 30). The values tabulated here are different from the original ones given in ref. 30), since the method of average for electron scattering is modified in accordance with Gold *et al*: Phys. Rev. **103** (1956) 1250.
[b]. Ref. 18).
[c]. Ref. 31).

Table (5-2). Scatter of the D_d^V values derived indirectly from eq. (5.1) with the help of the conduction band deformation potential constants obtained by three groups in Table (5-1). In the first column, three representative values of $dE_g/d\ln V$ are given to start with. Case *a*, Case *b* and Case *c* correspond to *a*, *b* and *c* in Table (5-1), respectively.

$dE_g/d\ln V$ (eV)	Case *a* (eV)	Case *b* (eV)	Case *c* (eV)
−3.8[28]	−2.0	−0.5	−2.1
−5.7[28]	−0.1	1.4	−0.2
−3.2[29]	−2.6	−1.1	−2.7

In summary, it should be stressed that though the accurate determination of the band parameters of the valence band of germanium is difficult because of the Γ_{25}' degeneracy, the present method which utilizes cyclotron resonance technique associated with uniaxial stress makes it possible to determine them much more accurately than the previous works. The newly obtained set of parameters will no doubt facilitate the future discussions of the dynamics of the holes in germanium.

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