Even the relatively simple resistance measurements under elastic shock loading cannot be confidently interpreted from shock-compression data alone; it is necessary to call upon related atmospheric and elevated pressure studies. Fortunately, a well-founded picture is available for germanium [64P1] in which theory and experiment have been well reconciled. Depending upon the strain magnitude, the electrical conductivity of germanium under [111] and [100] uniaxial strain is dominated by either anisotropic-strain-induced electron population transfer, anisotropic-strain-induced splitting of the valence band maximum, or strain-induced shifts in energy gap. Uniaxial [111] strain greatly simplifies the conduction band in that sufficiently large strains convert the multivalley conduction band to a single valley conduction band. On the other hand, the valence band becomes more complicated as the degeneracy of the maximum is lifted and energy levels are split. The properties of holes in such a strained configuration present the largest uncertainty.

To plan and fully analyze experimental studies of the effect of adiabatic elastic strain on the electrical conductivity of germanium, C.L. Julian (formerly of this Laboratory) has developed a computer code, "Santa Fe", whose main subroutine, "Chili", calculates conductivity and related diagnostic parameters for [111] and [100] uniaxial strains, uniaxial stresses and hydrostatic pressure. Sources for the theory and data incorporated in the code are summarized in table 4.8.

Table 4.8
Reference sources for strain-dependent conductivity analysis incorporated in Julian's Santa Fe computer code*

Parameter	Author	Reference
General reference, **germanium	Paige	[64P1]
Population transfer model	Herring; Keyes	[55H1]; [60K1]
$np\,(0, T)$	Morin and Maita; Prince	[54M1]; [53P1]
M_n	Paige	[64P1]
$\mu_n\,(S, T)$	Schetzina and McKelvey	[69S2]
$M_p\,(S, T)$	Julian and Lane	[73J3]
$\mu_p\,(S, T)$	Asche et al.	[66A4]
$(\Xi_d + \frac{1}{3}\Xi_u + a) = -4.03$ eV	Paul; Paul and Brooks	[63P1]; [63P3]
b, d	Pollak and Cardona	[68P2]

* Notation: M_n and M_p represent the effective masses of electrons and holes, respectively. The term $(\Xi_d + \frac{1}{3}\Xi_u + a)$ is the change in energy gap with strain for the [111] valley minimum. Ξ_d is the deformation potential for dilation, Ξ_u is the deformation potential for shear and a is the deformation potential for the valence band maximum under hydrostatic pressure, b and d are shear deformation potentials for the valence band maximum for (100) and (111) shear strains, respectively.

** See also the more general work on strain dependencies by Bir and Pikus [74B2].

As is customary, the conductivity is described by independent transport of electrons and holes such that

$$\sigma = ne\mu_n + pe\mu_p, \tag{4.25}$$

where σ is the conductivity, n and p are the numbers of electrons and holes, respectively, μ_n and μ_p are mobilities of electrons and holes, respectively, and e is the electronic charge. If the sample contains ionized impurities denoted $N_A - N_D$, where N_A is the number of acceptor ions and N_D is the number of donor ions, the np product is

$$np = n^2 - (N_A - N_D)n. \tag{4.26}$$

The np product at a strain, S_1, and temperature, θ, $np(S_1, \theta)$ of interest can be shown to be

$$np(S_1, \theta)/np(0, \theta) = R_n R_p \exp(-\Delta E_g/k\theta), \tag{4.27}$$

where R_n and R_p are the ratios of density of states effective masses to the 3/2 power of the unstrained to strained electrons and holes, respectively, ΔE_g is the change in energy gap and k is Boltzmann's constant.

Once values for R_n, R_p and ΔE_g are calculated at a given strain, the np product is extracted and individual values for n and p are determined from eq. (4.26). The conductivity can then be calculated from eq. (4.25) after the mobilities are calculated. The hole mobility is the principal uncertainty since it has only been measured at small strains. In order to fit data obtained from elastic shock-loading experiments, a hole-mobility cut-off ratio is used as a parameter along with an unknown shear deformation potential. A best fit is then determined from the data for the cut-off ratio and the deformation potential.

The effect of [111] uniaxial strain on conductivity is illustrated in fig. 4.9 by the calculated solid line for which the Santa Fe Code incorporated the parameters shown. (The datum points are to be described later.) At low strain the conductivity change is dominated by changes in electron

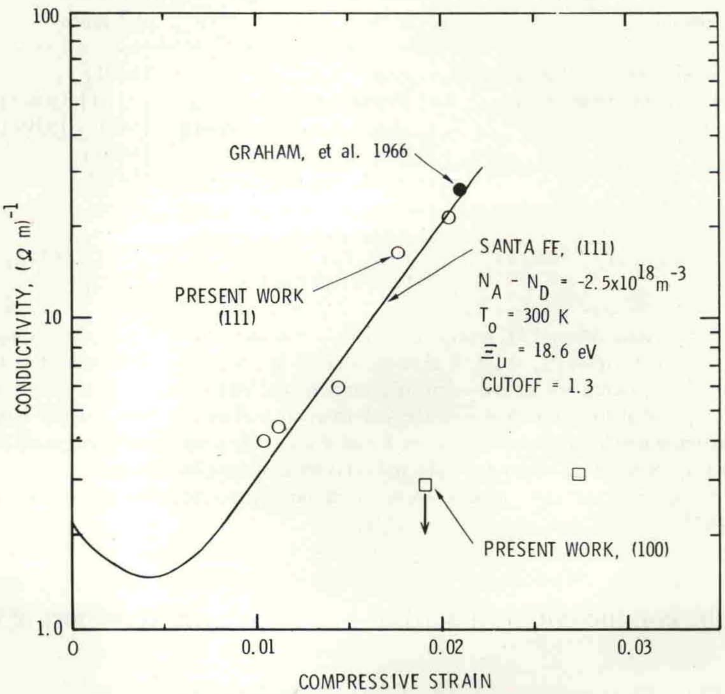

Fig. 4.9. The conductivity of uniaxially-compressed germanium is strongly influenced by changes in energy gap as well as strain-induced changes in mobilities and effective masses. The solid line is calculated with the computer code Santa Fe using impurity carrier concentrations, shear deformation potentials and a hole mobility cut-off ratio chosen to represent the present data. The cut-off affects the location of the minimum while the deformation potential controls the slope at large strain.