A detailed study of trapping in silicon has been performed by Hornbeck and Haynes.[1] Their results show that in a particular p-type silicon sample there was a level of traps 0.57 ev below the conduction band (these are called shallow traps) and a second level of deep traps with 0.79 ev activation energy. These levels are illustrated in Fig. 8-13. The minority-carrier lifetime was $\tau_n = 20 \times 10^{-6}$ sec, the relaxation time of the shallow traps was measured to be $\tau_t = 10^{-2}$ sec, and the relaxation time of the deep traps was $\tau_t = 260$ sec.

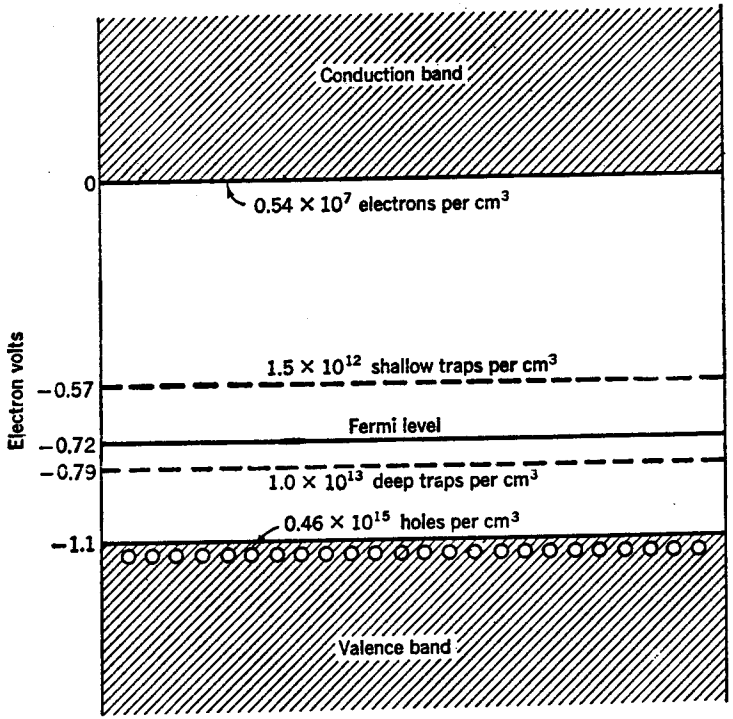

FIG. 8-13. Density and relative energy of electron traps in a specimen of p-type silicon. (*From J. A. Hornbeck and J. R. Haynes, Phys. Rev., vol. 97, p. 316, Jan. 15, 1955.*)

These three separate time constants were determined by measuring the photoconductivity of the semiconductor as a function of time. This method is illustrated in Fig. 8-14. First, the p-type sample is uniformly illuminated with a light source so strong that the electron traps are saturated (completely filled with electrons). Then, at time

[1] J. A. Hornbeck and J. R. Haynes, Trapping of Minority Carriers in Silicon: I, P-type Silicon, *Phys. Rev.*, vol. 97, pp. 311–321, Jan. 15, 1955; and J. R. Haynes and J. A. Hornbeck, Trapping of Minority Carriers in Silicon: II, N-type Silicon, *Phys. Rev.*, vol. 100, pp. 606–615, Oct. 15, 1955.

$t = 0$, the light is abruptly removed, and the conductance is measured while the sample returns to thermal equilibrium. The first change in conductance shown in Fig. 8-14 (at $t \approx 20 \times 10^{-6}$ sec) is due to the recombination of the untrapped excess carriers. The remaining excess electrons are in traps and cannot contribute to the conductivity, but there are an equal number of excess mobile holes which are needed to balance the charge of the trapped electrons. Therefore, the conductance of the sample does not return to its thermal-equilibrium value until the excess holes are removed; this occurs when the electron traps are emptied

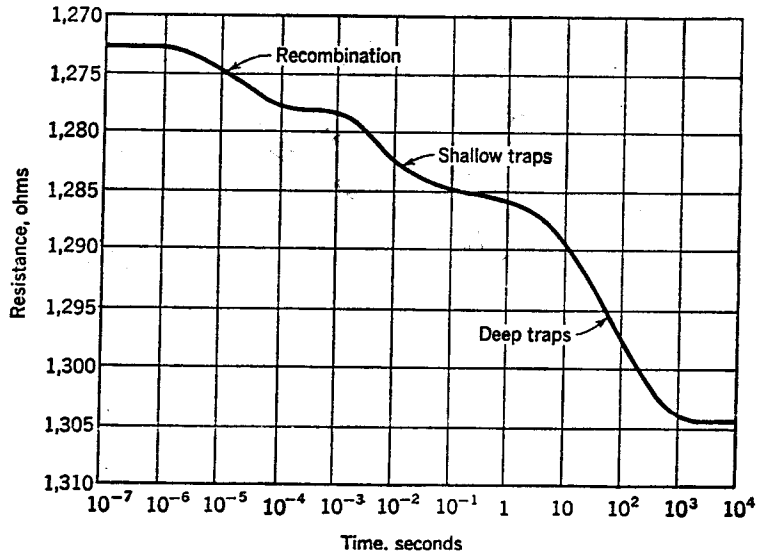

FIG. 8-14. Resistance of a p-type silicon specimen, which has been illuminated with a strong light, as a function of the time from the instant when the light is abruptly removed. (*From J. A. Hornbeck and J. R. Haynes, Phys. Rev., vol. 97, p. 313, Jan. 15, 1955.*)

and the excess carriers recombine. The two other conductance changes shown in Fig. 8-14 (at approximately 10^{-2} and 260 sec) correspond to the emptying of shallow and deep electron traps, in that order.

Two different trapping levels have been identified in n-type silicon.[1] There are some hole traps 0.45 ev above the valence band, with

$$\tau_t = 4.5 \times 10^{-2} \text{ sec}$$

The other level of hole traps is 0.72 ev above the valence band, with $\tau_t = 300$ sec. The trap densities have varied from less than 2×10^8 to approximately 10^{16} traps per cubic centimeter. These trap densities

[1] Haynes and Hornbeck, *ibid.*