where τ is the carrier lifetime, η is the quantum efficiency (i.e., number of carriers generated per photon), and n is the excess carrier density. Since this concentration is much larger than the background doping level of the photoconductor, the steady-state concentration becomes

$$n = G_e \tau. \tag{6}$$

The carrier lifetime is related to the characteristics that if the light is taken off, the concentration would decay with time at a rate of

$$n(t) = n(0)\exp\left(\frac{-t}{\tau}\right). \tag{7}$$

For an intrinsic photoconductor, the photocurrent flowing between the electrodes is

$$I_p = \sigma \mathscr{E} WD = (\mu_n + \mu_p) nq \mathscr{E} WD \tag{8}$$

where $\mathscr{E}$ is the applied electric field inside the photoconductor, and $n = p$. Substituting n of Eq. 5 into Eq. 8 gives

$$I_p = q\left(\eta \frac{P_{\text{opt}}}{h\nu}\right)\frac{(\mu_n + \mu_p)\tau \mathscr{E}}{L}. \tag{9}$$

If we define the primary photocurrent as

$$I_{ph} \equiv q\left(\eta \frac{P_{\text{opt}}}{h\nu}\right), \tag{10}$$

the photocurrent gain G_a from Eq. 9 is

$$G_a = \frac{I_p}{I_{ph}} = \frac{(\mu_n + \mu_p)\tau \mathscr{E}}{L} = \tau\left(\frac{1}{t_{rn}} + \frac{1}{t_{rp}}\right) \tag{11}$$

where t_{rn} ($= L/\mu_n \mathscr{E}$) and t_{rp} ($= L/\mu_p \mathscr{E}$) are the electron and hole transit times across the electrodes. The gain depends upon the ratios of carrier lifetimes to the transit time and is a critical parameter in photoconductors. For high gain, the lifetime should be long, while the electrode spacing should be short and mobilities high. A typical gain of 1,000 is readily obtained, but higher gains up to 10^6 have been achieved (Table 1). On the other hand, the response time of a photoconductor is also determined by the lifetime. So there is a trade-off between gain and speed. A photoconductor generally has a response time much longer than that of a photodiode.

The high gain can be limited by the maximum field at breakdown. Another effect is due to the minority-carrier *sweep-out*.[3] Under a moderate field, the majority carriers (electrons) have a higher mobility and their transit time is shorter than the carrier lifetime. Meanwhile, the minority carriers (holes) are slower and their transit time is longer than the carrier lifetime. Under this condition, electrons are swept out of the detector quickly, but the holes demand charge neutrality and more electrons are supplied from the other electrode. Through this action, electrons are going through the detector many loops during the carrier lifetime, and this action is responsible for the gain. At very high fields, holes also move with a transit time shorter than the lifetime.