Optical and Electrical Detection of Photocarrier Time of Flight

In a recent Letter Grahn, Vardeny, Tauc, and Abeles\(^1\) reported picosecond-domain electron drift-mobility measurements in amorphous hydrogenated silicon multilayers utilizing a novel time-of-flight technique: The transit of the photogenerated electrons across a thin layer was \textit{optically detected} by use of the difference between the electron absorption cross sections of states in the bulk of the film and at interfacial traps. In general optical detection approaches are important alternatives to conventional \textit{electrical detection} of time of flight because of superior time resolution. In this Comment we first discuss the quite distinct relationships of the optical and electrical signals to the underlying photocarrier transport. Given this distinction the similarity of the transient optically detected signal of Grahn \textit{et al.} to previous electrically detected signals is remarkable; we show that the similarity arises because the optically detected signal for uniformly absorbed photoexcitation has the \textit{same form} as the electrically detected signal for surface-absorbed photoexcitation.

As discussed in Ref. 1, the change in the photoinduced absorption coefficient \(\Delta a(t)\) of a constant areal density \(N\) of photocarriers generated at \(t = 0\) measures the fraction of photocarriers \(f(t)\) which have arrived at the interfacial traps:

\[
\Delta a(t) \propto N \left[ f(t) a_1 + (1 - f(t)) a_2 \right].
\]

\(a_1\) is determined by the optical properties of interfacial states and \(a_2\) by bulk states. The time derivative of \(\Delta a(t)\) is the signal reported in optical detection; it is proportional by charge continuity to the current density \(j(d, t)\) of photocarriers into the interfacial traps at \(x = d\), and optical detection is thus a photocarrier \textit{arrival time} spectroscopy.\(^2\)

The electrically detected signal is the displacement current \(i(t)\) obtained from a circuit which also establishes a bias voltage \(V\); for convenience \(i(t)\) is normalized by the specimen area normal to the external field \(F\). Then \(j(x, t)\) in the specimen and \(i(t)\) in the circuit are related by

\[
i(t) = (V/F) \left[ \int_0^d j(x, t) dx \right].
\]

\(V/F\) is the interelectrode spacing; note that (1) simply equates the power provided by any external voltage to the photocarrier dissipation in the external field.

The distinction between the transient currents \(i(t)\) and \(j(d, t)\) is illustrated in Fig. 1 for a \textit{nondispersive} material (drift mobility independent of time) for two types of photoexcitation: surface photocarrier generation, as is usually employed in time-of-flight experiments, and uniform generation, as used in the optical-detection experiment.\(^1\) The figure is elementary. The displacement current for surface generation \(i_0(t)\) and the interfacial current for uniform generation \(j_u(d, t)\) appear to be very similar.

The two currents are in fact equal under more general conditions including dispersion.\(^3\) Consider the current density \(j_0(x, t)\) due to near-surface generation of areal density \(Q\) of charge. \(j_u(x, t)\) for uniform generation of the same areal density is obtained by the integration of \(j_0(x, t)\):

\[
j_u(x, t) = d^{-1} \int_0^d j_0(x - x', t) dx'.
\]

This equation is valid if the effects of surface inhomogeneity in the specimen are negligible; the resulting practical restriction to homogeneous materials with small diffusion currents is usual for time-of-flight experiments. With use of (1) the required equation is obtained:

\[
j_u(d, t) = d^{-1} \int_0^d j_0(d - x', t) dx' = (V/Fd) i_0(t).
\]

\(V/Fd\) is the areal electron charge.

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