Time-resolved dark injection in dispersive media. Doped a-As_2Se_3

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Time-resolved hole injection following application of a step field has been studied in a series of doped a-As_2Se_3 films fitted with Au contacts. In either undoped a-As_2Se_3 or in a-As_2Se_3 doped with Ga (which increases hole drift mobility), injection from Au does not occur under space-charge-limited conditions. In Ga-doped samples both the small-signal transient responses and the dark-current steady state, although not space-charge limited, are controlled by an injection efficiency which is found to increase monotonically with hole drift mobility. In a-As_2Se_3 films doped with 4200-ppm Cu, hole drift mobility is reduced by two orders with respect to the undoped film at the same field. Step-field-excited transient response, dark-current steady-state behavior, and drift-mobility data are, in this case, all susceptible to a self-consistent analysis using conventional space-charge-limited theory. In particular, despite the large dispersion in carrier arrival times perceived in time-of-flight experiments, steady-state dark currents, calculated using the experimental transit time, are coincident with measured values. In these highly dispersive media, however, the transit time, defined in the context of a stochastic model is disproportionately weighted by the fastest carriers. It is these faster transit events which control the steady-state current.

I. INTRODUCTION

The transition from transient conditions to a dark-current steady state following the application of a field step is studied in a-As_2Se_3 films doped with various metallic impurities. Figure 1 shows that the hole drift mobility in a-As_2Se_3 can be changed over four orders of magnitude by doping.[1] At fields where the transit time of injected carriers becomes comparable to the dielectric relaxation time, the bulk demands that the contact supply about a CV of charge per transit time. (C is the sample capacitance, V the applied voltage.) This rate of injection is required to sustain space-charge-limited (SCL) conditions.[2] A contact capable of injecting at this rate is operationally classified as ohmic. A contact which falls short of sustaining SCL conditions but which can supply excess charge for at least several transit times is called a finite injector.[3] Changing the hole drift mobility (transit time) modulates the demand made by the bulk for injected charge from the contact. Therefore a finite contact can become ohmic as mobility is reduced by doping, and conversely.

Au, like Bi, Ni, Ag, Sn, C, and Ga forms a finite injecting contact[4-6] on undoped a-As_2Se_3 above 10^4 V/cm. In this field range the transient response of an Au contact can be analyzed in a small-signal approximation. It can be shown that the steady-state currents measured in undoped a-As_2Se_3 at high field are always limited by contact injection efficiency. The time-dependent response of these emission-limited dark currents to step-field excitation reflects the interplay of a decaying reservoir with the dispersive transport process and has been so modeled.[4,6] On the other hand, steady-state SCL currents have never been observed in a-As_2Se_3 or other equally dispersive media.

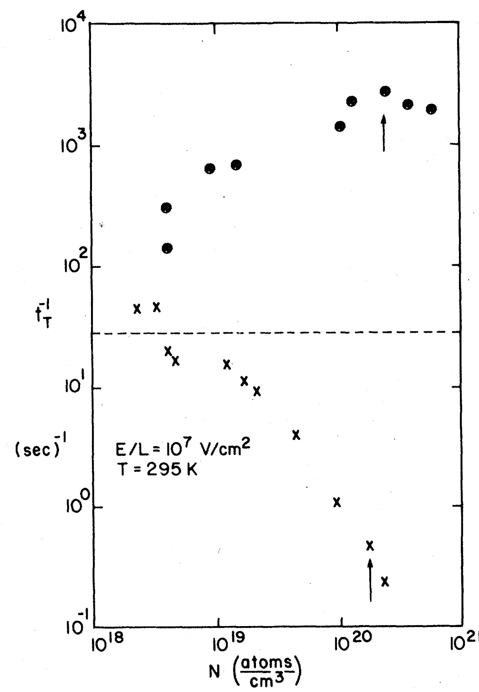

FIG. 1. Inverse hole transit time versus concentration of gallium, represented by points and Cu represented by ×'s in a-As_2Se_3 films when $E/L = 10^7$ V/cm^2. $T = 295$ K. Dashed line is inverse transit time of holes in undoped bulk (the reference case). Vertical arrows highlight specimens which form the focus of the present study. 7000-ppm-Ga-doped a-As_2Se_3 and 4200-ppm-Cu-doped a-As_2Se_3 represented by filled circles and crosses, respectively.

In the present study Au contacts are used. Measurements are always carried out at fields where SCL conditions would prevail if the contacts used were ohmic.

In the samples doped with Ga to increase hole drift mobility the Au contact remains finite as expected. The observed behavior is therefore generically similar to the behavior of Au on the undoped bulk and contrasts with observations to be described on the lowest mobility samples, those doped heavily with Cu. One new result augments our earlier observations[4-6] on emission-limited (finite) injection in (undoped) a-As_2Se_3. By analyzing both transient injection and the steady-state dark current in a series of Ga-doped samples, it can be shown that injection efficiency increases in response to the increased mobility (Sec. III B).

In the lowest mobility samples a self-consistent analysis shows that the Au contact is ohmic over the experimentally accessed field range. It is on time-resolved dark injection in these samples that we focus primarily (Sec. III C). In this case it will be shown that in all important respects dark injection conforms to the predictions of conventional space-charge-limited theory[7,8] just as it would in nondispersive systems. The equilibrium dark current is found to be trap-free[3] SCL. Trap-free SCL current is exclusively controlled by drift mobility of the injected carrier.[2,3] The ability to measure the transition from transient conditions to an SCL dark-current steady state, which is enabled by doping a-As_2Se_3, therefore provides the first opportunity to fully examine the evolution in time of parameters that characterize transport in a highly dispersive medium.

II. EXPERIMENTAL

Amorphous As_2Se_3 films in the thickness range 40–60 μm were prepared by evaporation at about 1 μm/min from stainless steel open boats onto Al substrates held at 458 K in a vacuum harder than 5×10^{-6} torr. Samples doped with Cu and Ga were prepared by co-evaporating the dopant metal and the bulk As_2Se_3 glass.[1]

For time-resolved injection measurements evaporated Au contacts were applied to the exposed film surface. Positive dc bias was applied to the top contact using a mercury relay to minimize voltage rise time and avoid contact bounce. Current traces were then recorded using a storage oscilloscope. Time-of-flight (TOF) experiments were performed using a pulsed flash of surface absorbed light in an apparatus which allowed direct display of log I versus log t from which the transit time was measured.[10,11] TOF measurements were made in the I mode where the circuit response time is kept shorter than the carrier transit time.[9] The amount of charge in transit was always much less than CV. In this latter limit charge transits the sample in a uniform field. Evaporated Al contacts which block hole injection[5] in the dark were used for most of the TOF experiments in order to minimize the perturbing influence of trapped, dark injected, space charge. For the cases of undoped a-As_2Se_3 and Ga-doped a-As_2Se_3 transit pulses could also be observed following flash excitation through the semitransparent Au contacts used for dark-injection measurements. For the lowest mobility specimens (i.e., those doped with 4200-ppm Cu) small-signal transit pulses could not be observed on photoexcitation through the semitransparent Au contact making the use of Al mandatory in this case. A variable temperature ambient was provided by a programmable temperature chamber in which temperature stability was regulated to better than 1 K.

III. RESULTS AND DISCUSSION

In the following the transition from transient conditions, following step-field excitation, to the establishment of a dark-current steady state is studied. The field regime of interest, typically $E \geq 10^4$ V/cm is that for which any excess injected hole is swept through the bulk before it can be locally neutralized.[4] It is only when the latter condition applies that transit pulses, surface excited by a light flash in a time-of-flight (TOF) experiment or dark-current transients clearly associated with the transport of excess injected positive space charge are observed.[5,9]

Measurements on undoped a-As_2Se_3, the reference system, are described and compared to measurements on a-As_2Se_3 films doped with Ga, which increases, and Cu which depresses, the hole drift mobility with respect to the undoped film. Evaporated Au contacts are always used.

The following description of the dark-injection process would be appropriate if contact to these films could be made ohmic and the complicating impact of carrier dispersion could be ignored to the extent that a hole mobility remained operationally defined in terms of a suitably averaged experimental transit time.[7] The response of the dark current in these films to step-field excitation would be a transient space-charge-limited current (TSCLC), $i(t)$. The TSCLC would exhibit a local maximum at time t_m following application of a field step where

$$t_m = (a)t_T\,; \tag{1}$$

t_T is the hole transit time measured under small-signal conditions by TOF and a is a parameter always close to unity which varies according to the observed field dependence[10] of t_T. Conventionally $a=0.8$, but it is reduced[10] by about 10% in a-As_2Se_3 because the inverse transit time is quadratic in its field dependence. The magnitude of the TSCLC at its local maximum $i(t_m)$ would be

$$i(t_m)=(b)CV/t_T\,, \qquad (2)$$

where C is the sample capacitance, V the applied voltage, and b a parameter which varies with the field dependence of the experimentally determined t_T. When the field dependence of t_T^{-1} is linear $b=1.36$. b has been determined[10] to be about 1 in a-As_2Se_3. The transition to a dark-current steady state i_{ss} in the absence of any further trapping between time t_m and the time to establish current equilibrium is

$$i_{ss}=(c)CV/t_T\,, \qquad (3)$$

where c reflects the field dependence of t_T^{-1}. c is 0.8 in a-As_2Se_3. The experimental transit time already incorporates the effects of trapping between $t=0$ and $t=t_T$. If trapping between t_m and the time to establish current equilibrium were important, then the current would drop[3] (the drop is often observed[3] to be many orders of magnitude) to a trap-limited steady state. In the latter case the functional dependence of the steady-state current on field and dimensional parameters would depend on the trap distribution and the position of the Fermi level.[2,3] Studies of the transition to trap-limited SCL current equilibrium have frequently been employed as an important probe of trap distributions in semiconductors and insulators.[3] The preceding is a backdrop against which experimental results are now considered.

A. a-As_2Se_3

Figure 2(a) schematically represents a dark-injection transient and defines the parameters of interest, t_m and $i(t_m)$. In Fig. 2(b) the transit time computed from dark-injection current maxima using Eq. (1) (dark circles) is compared to the actual transit time determined by TOF measurements under small-signal conditions at room temperature on the same sample (open circles). The transient dark-current maximum occurs several transit times after application of a field step contrasting with the behavior predicted by Eq. (1), but t_m is found to have the same activation energy[4] as t_T. In Fig. 3 we compare the measured dark-injection transient current maxima $i(t_m)$ (circles) with the transient SCL current maxima (triangles), calculated by substituting experimentally determined hole transit times and sample capacitance in Eq. (2). Dark-injection peaks $i(t_m)$ are typically more than an order of magnitude smaller than the calculated values as shown. Once again the measurements show significant deviation from the calculated space-charge-limited behavior. To account for these features we proposed[4,6] that the Au contact forms a finite hole accumulation zone on a-As_2Se_3. Holes are supplied to the bulk from this accumulation zone with a diminishing efficiency in the time after application of a voltage step. The supply rate is always significantly less than the CV per transit time that would be injected by an ohmic contact. Under these circumstances it was shown using a model cast in the small-signal approximation, that the dark-current transient response reflected the interplay of reservoir population kinetics and the rate of hole extraction.[4] The dark-current steady state, in this case, reflects the injection efficiency of the contact interface which can be, but is not necessarily, a function of the hole mobility. In Fig. 4 the steady-state dark current is compared to the current calculated using Eq. (3), that would be sustained at the same

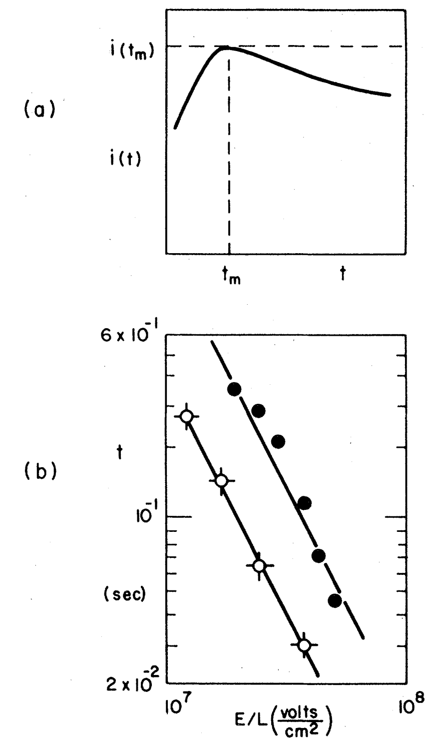

FIG. 2. (a) Schematic depicting generalized dark-current response to step-field excitation defines parameters of interest but is not an accurate rendition of experimental transient. t_m is time after field application when current $i(t_m)$ achieves its maximum value. Field is such that any excess injected hole transits the sample before it can be neutralized. (b) $a^{-1}t_m$, dark circles, from dark-injection transient response compared with t_T, open circles, measured by TOF in same undoped a-As_2Se_3 sample as a function of E/L. $T=295$ K.

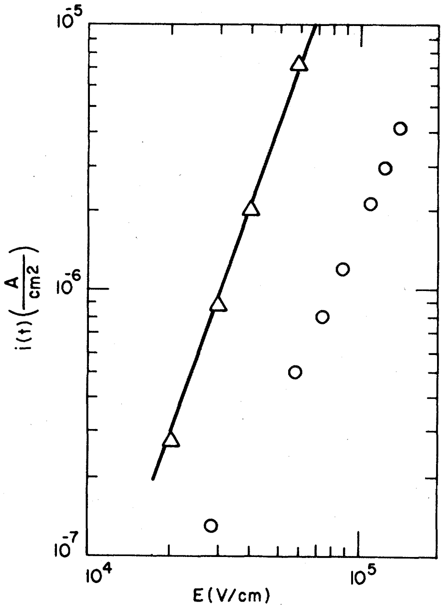

FIG. 3. Space-charge-limited current maxima, triangles, computed using experimental transit times in Eq. (2) are compared to measured $i(t_m)$, circles, at various fields in a-As_2Se_3. $T=295$ K, $L=31$ μm.

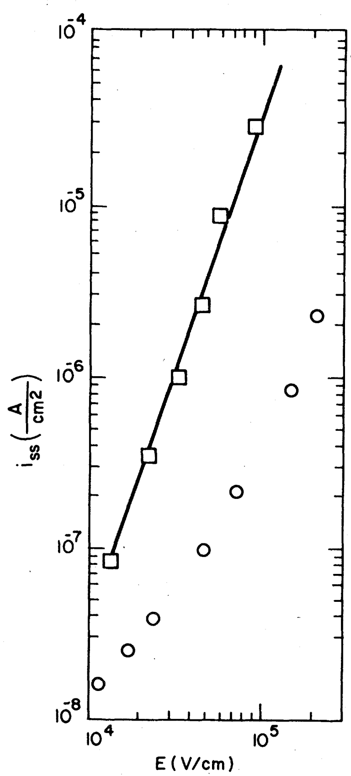

FIG. 4. Trap-free SCL current, squares, calculated using experimental transit times in Eq. (3) compared with steady-state current i_{ss}, circles, measured in the same undoped a-As_2Se_3 film at various fields. $T=295$ K.

fields if the contact were ohmic and there were no trapping beyond that which establishes the transit time measured in TOF. The measured current is significantly smaller than the calculated trap-free SCL current; neither is it found to conform to the scaling laws appropriate to either trap-free or trap-limited space-charge-limited conditions.[2,3] The steady-state dark currents illustrated in Fig. 4 are injection-efficiency controlled.

B. Ga-doped a-As_2Se_3

Doping a-As_2Se_3 with indium or Ga increases the hole drift mobility.[1] At 7000-ppm Ga (3×10^{20} Ga atoms cm^{-3}) the increase in drift mobility is about two orders of magnitude compared to undoped a-As_2Se_3 as illustrated in Fig. 1. Under space-charge-limited conditions the demand for injected current made on an ohmic contact by the bulk increases directly with mobility of the injected carrier. When the current is injection-efficiency controlled the relationship between carrier mobility and supply efficiency is not as readily apparent. Injection mechanisms in which efficiency scales with mobility have, however, been reported previously[11] and models to explain this behavior proposed. In one simple physical picture, for example, a carrier in the interfacial region is thermally promoted to a excited state in which it becomes free to drift away from the contact with the bulk mobility under action of the applied field. The probability of its return to the reservoir diminishes as the carrier is extracted further from the interfacial region. Supply efficiency which reflects the competition between the probabilities for escape and deexcitation to a reservoir state is then expected to scale with mobility and applied field. In Fig. 5 the t_m and actual hole transit time are again compared. The bulk dielectric relaxation time is estimated[1] to decrease by about two orders of magnitude and this, together with a hole drift mobility now increased two orders of magnitude, are responsible for the narrow experimental window between $E/L=7\times10^6$ V/cm^2 and 1.5×10^7 V/cm^2. In fact, below 4×10^6 V/cm^2, t_m, which has become essentially field independent, is a measure of this dielectric relaxation time. The similarities evident in comparing Figs. 2 and 5, Figs. 6 and 3, and Figs. 7 and 4 indicate the generic behavior observed on increasing the hole drift mobility in a-As_2Se_3. In all cases the transients observed remain small-signal responses and the steady state remains injection-efficiency controlled just as in undoped a-As_2Se_3 under the same conditions. In Fig. 8 the injection-current maxima (half-filled circles) and dark-current steady-state values, plotted as a function of field,

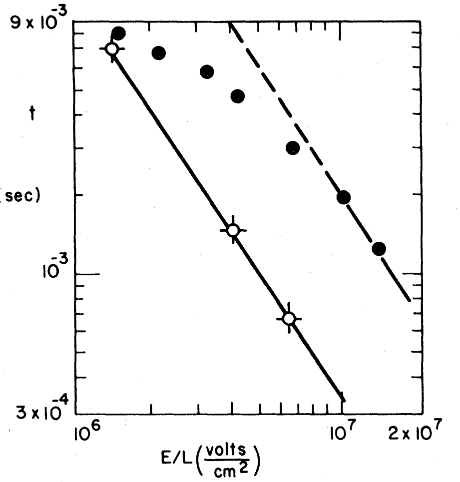

FIG. 5. $a^{-1}t_m$, filled circles, from dark-injection transient response compared with t_T, open circles, measured by TOF in same a-As_2Se_3 film doped with 7000-ppm Ga as a function of E/L. $T = 295$ K.

are compared in 7000-ppm Ga-doped a-As_2Se_3 (filled circles) and undoped a-As_2Se_3 (open circles), respectively. Figure 8 illustrates directly an injection efficiency which is responsive to a change in the bulk hole drift mobility. Vertical arrows display evolution of the current from transient to steady-state conditions.

C. Cu-doped a-As_2Se_3

Cu doping results in a progressive decrease in the hole drift mobility of a-As_2Se_3. At 4200-ppm Cu (2×10^{20} Cu atoms cm^{-3}) the hole drift mobility is about two orders of magnitude lower than the undoped sample as illustrated in Fig. 1. The demands made on an ohmic contact to supply hole current to the bulk under SCL conditions would in this case be significantly diminished compared to those made by the undoped bulk at the same field.

In Fig. 9 we compare the transit time computed from t_m using Eq. (1) with hole transit times measured via TOF. There is one important experimental qualification in this case. Whereas Au contacts could be used for both TOF and dark-injection measurements in the samples described previously, it is no longer, in this case, possible to observe small-signal hole transit pulses upon surface photoexcitation through Au and use of evaporated Al becomes mandatory for the time-of-flight experiment. This observation is of intrinsic interest because it should not be possible to flash excite a small-signal transit pulse through a semitransparent ohmic contact.[6] The conditions which must in fact be satisfied to observe a transit pulse in a light-flash-induced small-signal time-of-flight

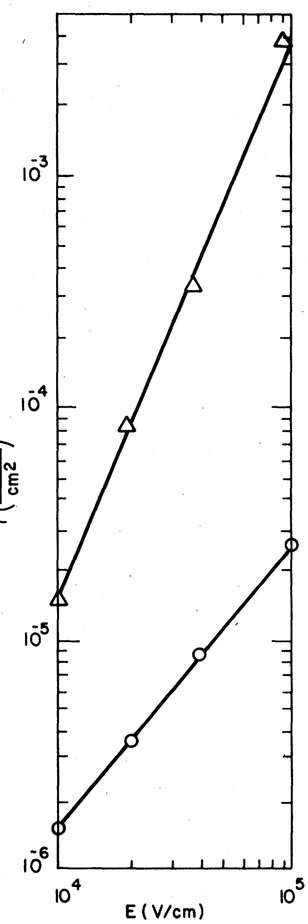

FIG. 6. Space-charge-limited current maxima, triangles, computed using experimental transit times in Eq. (2) are compared to measured $i(t_m)$, circles, at various fields in a-As_2Se_3 doped with 7000-ppm Ga. $T = 295$ K.

experiment are precisely those under which an ohmic contact would already inject about one CV of charge per transit time in the dark (SCL injection). The rate of injection under these conditions could not be significantly perturbed by a weak flash of surface absorbed light. The latter observation thus provides the first suggestion that Au forms an ohmic contact on these heavily Cu-doped a-As_2Se_3 films.

Figures 9–13 will clearly demonstrate that SCL conditions are sustained by Au contacts on these samples. Figure 9 illustrates, for example, that dark-injection cusps now provide a direct measure of the transit times. The transit times computed by substituting the experimental quantities t_m in Eq. (1) coincide with hole transit times measured via TOF. The behavior illustrated in Fig. 9 contrasts with the corresponding cases previously discussed in connection with Fig. 2 and 5. In Fig.

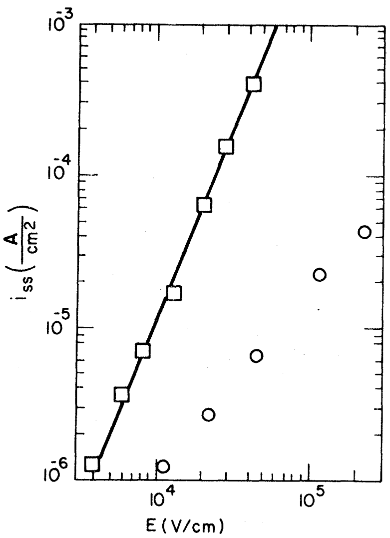

FIG. 7. Trap-free SCL current, squares, calculated using experimental transit times in Eq. (3) compared with steady-state current i_{ss}, circles, measured in the same a-As_2Se_3 film doped with 7000-ppm Ga at various fields. $T = 295$ K.

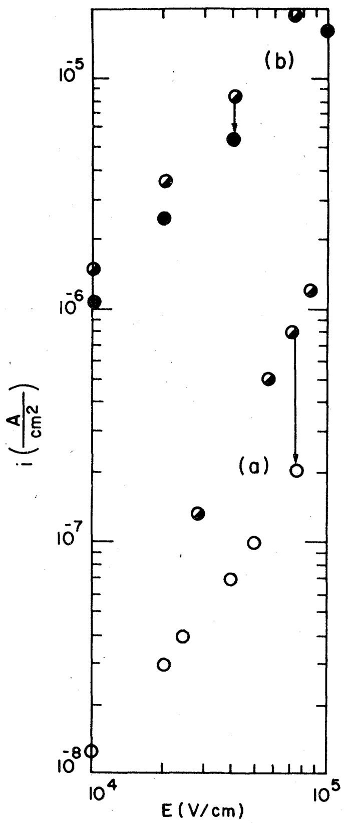

FIG. 8. The quantities $i(t_m)$, half-filled circles, and i_{ss}, the measured steady-state dark current, filled and open circles, are compared at various fields in (a) a-As_2Se_3 and (b) a-As_2Se_3, respectively, doped with 7000-ppm Ga. Vertical arrows indicate direction of time evolving current. $T = 295$ K.

10 we compare as a function of reciprocal temperature the phenomenological mobility $d/E\ (t_T)^{-1}$ determined from TOF measurements and represented by open circles with its counterpart $(d/E)at_m^{-1}$ determined from dark-injection current maxima at the same field (dark circles). Conformity with Eq. (1) persists as temperature varies. Activation energy of the drift mobility and of t_m at this field is 0.69 eV as illustrated. Fully complementary behavior is exhibited by the measured dark-injection current maxima plotted in Fig. 11, which now coincide with the SCL-cusp amplitudes calculated, by substituting experimental transit times in Eq. (2). Transient dark-injection currents clearly conform to the behavior predicted by conventional space-charge-limited theory. From the same experimental transit times we calculate the trap-free space-charge-limited steady-state dark current at room temperature using Eq. (3). In Fig. 12 open squares represent calculated, and filled circles the measured values of the dark current. The agreement indicated between these measured and calculated dark currents contrasts with the corresponding data shown for undoped and Ga-doped a-As_2Se_3 in Figs. 7 and 4, respectively. A crucial test to further verify conformity of dark-current measurements in these samples with the trap-free space-charge-limited calculation based on experimentally determined transit times is illustrated in Fig. 13. Displayed on a common inverse-temperature axis are the respective temperature dependences of the transit time (refer to the right ordinate scale) and the equilibrium SCL dark current achieved at the same field (refer to the left ordinate scale). The activation energy common to both measurements, 0.69 eV, is also the activation energy of t_m shown in Fig. 10. The equilibrium SCL dark current and inverse transit times thus have activation energies which are identical to within the accuracy of measurement, in conformity with Eq. (3). Slow equilibration with deep traps can cause further progressive diminution of the SCL dark current on a time scale often many orders of magnitude larger than that of the transit time itself. Current diminution was not observed even when the dark current was monitored for up to 30 min after application of a field step. There was thus no indication of additional, very slow equilibration with deep traps during the approach to steady state. To reiterate, the above observations would conventionally be taken as decisive evidence that a transiting hole must already have communicated with all available traps in the bulk

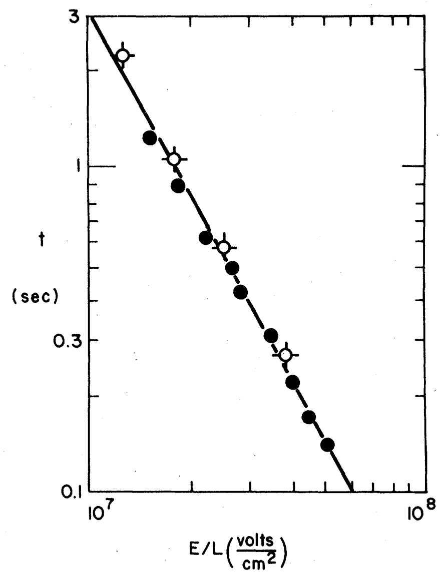

FIG. 9. $a^{-1}t_m$, filled circles, from dark-injection transient response compared with t_T, open circles, measured by TOF in same a-As_2Se_3 film doped with 4200-ppm Cu as a function of E/L. $T = 295$ K.

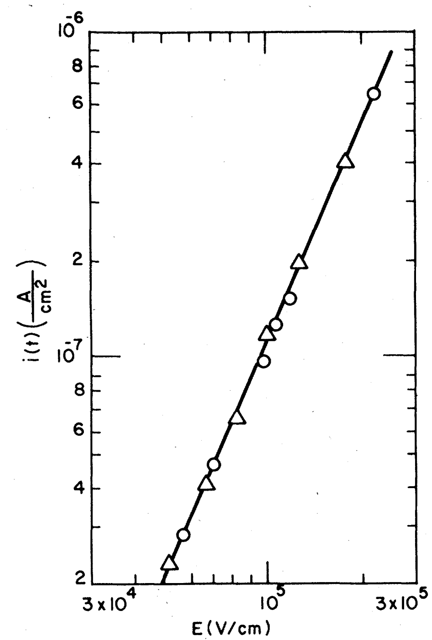

FIG. 11. Space-charge-limited current maxima, triangles, computed using experimental transit times in Eq. (2) are compared to measured $i(t_m)$, open circles, at various fields in a-As_2Se_3 film doped with 4200-ppm Cu. $T = 295$ K.

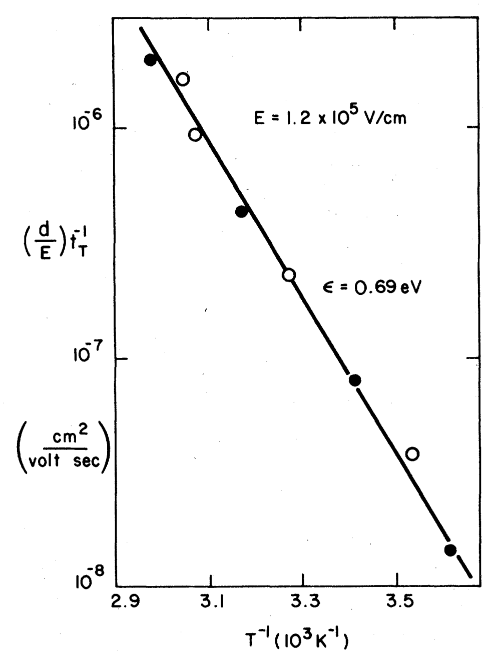

FIG. 10. Phenomenological quantities, $(d/E)(t_T^{-1})$, open circles, and $(d/E)a(t_m)^{-1}$, filled circles, are compared as a function of $10^3/T$, $E = 1.2 \times 10^5$ V/cm. Sample is a-As_2Se_3 film doped with 4200-ppm Cu. Activation energy, $\epsilon = 0.69$ eV.

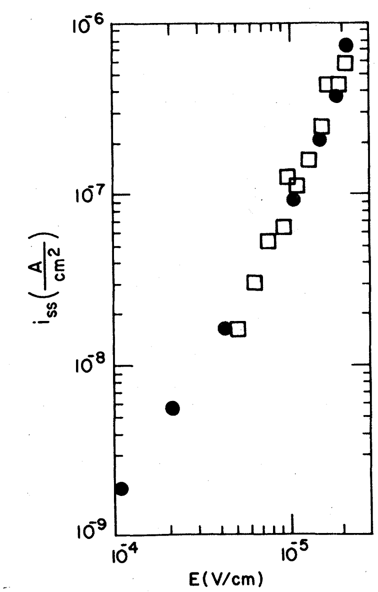

FIG. 12. Trap-free SCL current calculated using experimental transit times in Eq. (3), squares, compared with steady-state current i_{ss} measured in the same film, filled circles. Specimen is 4200-ppm-Cu-doped a-As_2Se_3. $T = 295$ K.

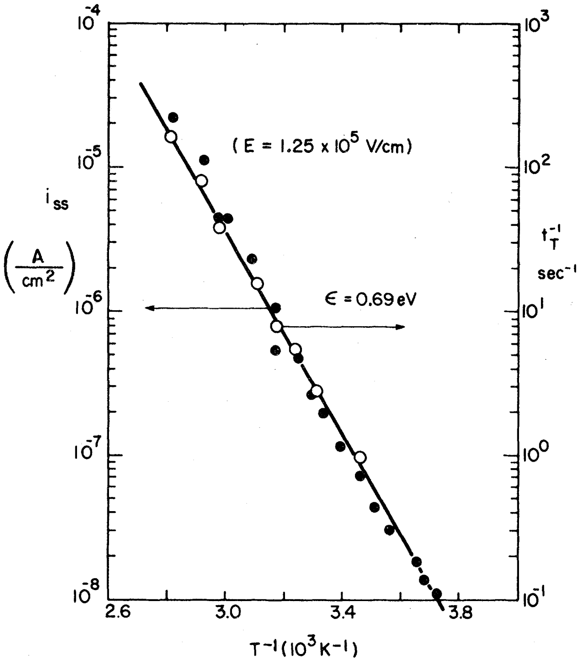

FIG. 13. Steady-state dark-current density, filled circles, and inverse transit times, open circles, are compared as a function of $10^3/TE = 1.25 \times 10^5$ V/cm. Sample is a-As_2Se_3 doped with 4200-ppm Cu. Activation energy is 0.69 eV. Horizontal arrows refer to corresponding ordinate scales.

and in that process established the measured transit time. There is no evidence of additional trapping on a much longer time scale.

The applicability of a trap-free SCL model[3] in which $(d/E)t_T^{-1}$ determined from TOF or transient dark-injection experiments operates as a phenomenological drift mobility would be less surprising were it not that these Cu-doped samples are at least as dispersive[1] as undoped a-As_2Se_3. For example, a similar result is obtained in a study[12] of hole photoinjection from a thin layer of a-Se into poly(N-vinyl carbazole), PVK. Hole transport in PVK is significantly less dispersive than in a-As_2Se_3. The parameter α which characterizes the degree of dispersion[13-15] and which is one in a-Se is 0.8 in PVK (Ref. 16) ($T \sim 300$ K) and in the range 0.4–0.5 in doped specimens of a-As_2Se_3.

For the case of conventional nondispersive or Gaussian transport the hole sheet photogenerated in a TOF experiment suffers only the usual thermal broadening (width $\propto t^{-1/2}$) during its traversal of the sample bulk.[17] In this latter case the transit time reflects a well-defined average mobility. Operationally the transit time can be regarded as the time when the current drops to half its initial value, or equivalently, the time when just half of the mobile photogenerated carriers in the sheet have arrived at and been extracted from the collecting electrode. In dispersive media, on the other hand, there is a wide distribution of carrier drift velocities and therefore a large but continuous spread in arrival times at the collecting electrode. According to the Scher-Montroll model[14] the mean position of the carrier packet is in this case predicted to remain quite close to the generating boundary even as the leading edge of the packet penetrates to the absorbing boundary. Dispersion of the transiting charge packet and its mean displacement in fact grow at the same rate.[14] An important prediction of the Scher-Montroll theory is that the transient currents observed in dispersive media during execution of a TOF experiment decay algebraically, exhibiting a change in slope just as the leading edge of the carrier packet arrives at and is extracted from the absorbing boundary.[13,14] The time when this slope demarcation occurs is readily identified experimentally and is taken as a convenient representation of the transit time. This transit time must be interpreted in a statistical framework.[15] In the case of a-As_2Se_3, for example, it has been shown that the break in slope occurs at a time corresponding to the extraction of only 15% of all the transiting holes.[13-15] In fact after five of these transit times have elapsed, 50% of the holes remain in the bulk.[14,15] In dispersive media the definition of an average transit time remains somewhat arbitrary. It is reasonable, however, to define an average transit time by analogy with the Gaussian case as that time when 50% of the transiting carriers have been extracted at the absorbing boundary. An average transit time would be about five of the experimentally defined transit times in these samples. The experimentally defined transit time in a highly dispersive system is disproportionately weighted by the most rapid transit events. It is significant that the transit times determined by slope demarcation in TOF experiments rather than a suitably averaged representation of all the carrier traversal times is found to describe the SCL dark-current steady state. Charge throughput under steady-state conditions is thus controlled by the fastest transits or, equivalently, the most efficient percolation paths in the system. The experimental transit times which are properly defined only in a statistical-model context now take on additional physical significance. Simulating a conventional drift mobility, they serve as a measure of charge throughput under equilibrium space-charge-limited conditions.

IV. CONCLUSIONS

(1) Doping a-As_2Se_3 with metallic impurities varies the hole drift mobility and therefore the

demand for injected current that would be imposed by the bulk on an ohmic contact under SCL conditions. Au contacts on a-As_2Se_3 are finite at high fields and not ohmic. The response of the Au contact to step-field excitation is to inject holes at a diminishing rate always much less than CV/t_T with the steady state ultimately controlled by the efficiency of supply. Doping with Ga increases hole drift mobility but the overall behavior of Au on the doped bulk remains qualitatively similar to its behavior on the undoped bulk. The Au contact remains finite on Ga-doped specimens but the rate of injection under both transient and steady-state conditions is enhanced. The latter is a particularly clear illustration of an injection-efficiency controlled (i.e., emission-limited) current which is nevertheless responsive to a change in bulk mobility.

(2) Doping a-As_2Se_3 with Cu depresses the hole drift mobility. At 4200-ppm Cu in a-As_2Se_3 the Au contact is ohmic, i.e., capable of sustaining space-charge-limited conditions. The transient response of the Au contact on these specimens to step-field excitation is an SCL transient. The transit time calculated from the current maximum is coincident with the transit time measured by small-signal time of flight at the same field on the same sample. These calculations incorporate the small numerical corrections derived by Chen[10] in order to correct the conventional[7,8] theory for the superlinear field dependence of the transit times observed in TOF experiments. The dark-current steady state in a given 4200-ppm-Cu-doped a-As_2Se_3 sample coincides with the trap-free space-charge-limited current calculated using the experimental hole transit times for that sample. The transiting charge in a TOF experiment evidently explores all the available traps and this interaction in turn establishes the measured transit time. The relationships between the above measurements and a slightly modified but otherwise conventional theory continue to apply as sample temperature is varied over a range spanning about 70 K. Complementary thickness dependence (scaling law) measurements would have been interesting. These were not attempted here because of our present inability to hold sample-to-sample doping density to the tolerance required to render such comparisons meaningful.

(3) In the TOF experiment a small packet of injected charge explores all of the available transport channels. In dispersive media these represent highly inequivalent paths and therefore give rise to a broad distribution in the arrival times of individual carriers. The transit time deduced from TOF measurements in such systems represent the arrival of only the leading edge of (or fastest carriers in) a highly dispersed charge packet.[14] Thus in 4200-ppm-Cu-doped a-As_2Se_3 50% of all the photogenerated holes are predicted to remain in transit even after five transit times have elapsed.[14,15] We have established that SCL dark currents calculated using these experimental transit times coincide with measured values. The latter result if interpreted in the framework of existing theory implies that when injection of holes becomes continuous under SCL conditions steady-state transport proceeds via the most efficient channels available in the system.

(4) Hole transit pulses in TOF remain very dispersive in 4200-ppm-Cu-doped a-As_2Se_3. Dispersion is interpreted as indicating incomplete communication, within a transit time, between transiting carriers and all available sites or traps. On the other hand, SCL dark-injection experiments, if interpreted conventionally, do not evidence (within experimental resolution) additional trapping between the transit time and the time required to achieve current equilibrium. This disparity which is not easily resolved at present is reminiscent of recent results reported by Borsenberger and co-workers on a molecularly doped polymer.[18] In the latter study transient transport observed under SCL conditions has been compared to small-signal (partial-injection) data collected on the same series of samples using the potential-discharge technique. The partial-injection data reported are characteristic of dispersive systems and therefore cannot be explained by ordinary models of potential discharge. On the other hand, SCL discharge is found to be in excellent agreement with predictions based on conventional theory. For example, when injection occurs under large-signal conditions anomalous thickness dependence of the mobility is not observed. Transport occuring under large-signal conditions must be influenced by strong interactions among the carriers in transit. Such interactions are neglected when a small charge packet transits ($Q \ll CV$) in a uniform field during a typical TOF experiment. Experiences with dispersive transport media in fact derive almost entirely from experiments carried out in the small-signal limit. It now appears that further probing of the relationship between transport occurring under small- and large-signal conditions in the same dispersive system could contribute an important additional perspective.

(5) This study demonstrates that a large dispersion in carrier arrival times, when observed in small-signal TOF, does not preclude for the case of SCL (i.e., large-signal) injection the applicability of conventional theory based on a phenomenological mobility concept.

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