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DENSITY OF STATES IN THE GAP OF $a$-As$_2$Se$_3$ BY PHOTOCURRENT TRANSIENT SPECTROSCOPY

D. Monroe, J. Orenstein and M. Kastner

MIT, Cambridge, MA, U.S.A.

Abstract. — Dispersive photocurrent in $a$-As$_2$Se$_3$, for $T \gtrsim 200$K, provides a measure of the density of localized states near the mobility edge. The power law transients correspond to a density of states which is exponential, $g(E) \sim \exp(-E/T_0)$, with $T_0 \approx 500$K. Recent measurements below 200K show deviations from the high temperature behavior. Possible explanations are discussed.

The transport properties of amorphous semiconductors are complicated by the interaction of the carriers with a large number of localized states. As a result, the mobility, as measured by either time-of-flight (TOF) or transient photocurrent (PC) experiments, is time-dependent (dispersive). Under favorable circumstances, however, such as those found in $a$-As$_2$Se$_3$ and $a$-Si:H$^2$, the current is simply related to the density of states (DOS) and can in fact be inverted to give the form of the DOS.

The familiar theories of dispersive transport are quite complex because they aim to treat both dispersion due to multiple trapping (MT) in states distributed in energy and dispersion due to hopping with a distribution of trap separations. The MT case yields to a much simpler and more physically direct analysis, however, because each trap interacts only with the transport states (above the mobility edge) and not with other traps. Actually, at finite temperatures, a high density of "traps" may in fact serve as transport states, and in this case the meaning of the "edge" is somewhat altered. In MT one considers only transfers between transport states and individual traps: (1) thermal excitation of carriers above the edge, with a rate $\nu(E) = \nu_0(E) \exp(-E/kT)$, and (2) trapping, with a rate per trap of $\nu_0(E) n(t)/N_c$, where $n(t)$ is the number of carriers above the edge, and $N_c$ is the number of transport states within $kT$ of the edge. Carriers which are close to the edge are quickly thermally excited and may be retrapped anywhere in energy, whereas deeper carriers stay trapped. As time goes on, more and more carriers are trapped deep in energy, and the number excited to the edge, which are responsible for transport, goes down. The dispersive transport simply reflects the slow process of thermalization of the carriers in the traps.

A moderate distribution of energies, even for constant $\nu_0(E)$, gives rise to an exponentially broad distribution of release rates. At a given time delay after the initial carrier injection (we use a 10ns dye laser pulse), there are two types of traps: shallow traps, with $\nu(E)t >> 1$, which are in equilibrium with the transport states, and deep traps, with $\nu(E)t << 1$, which have been filled by trapping but not emptied. The shallow traps have a Fermi distribution function, the same Fermi function which describes the occupation of the transport states. The deep traps are occupied only to the extent that mobile carriers have fallen into them since the initial excitation. These two regions are separated by a demarcation energy $E_d$ at which the excitation rate is comparable to the time delay ($\nu(E) t = 1$).

The PC data for As$_2$Se$_3$ can be fit assuming that $\nu_0$ is only weakly dependent on energy (with a value around $10^{12}$s$^{-1}$), and that the DOS is exponential: $g(E) = (N_L/kT_0) \exp(-E/kT_0)$, with $T_0 \approx 550$K. $N_L$ is the total number of localized states only if this distribution extends all the way to the edge. For this DOS, or any DOS

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++ Present address: Bell Laboratories, Murray Hill, New Jersey 07974

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FIGURE 1. Amorphous As$_2$Se$_3$ is excited with a 10ns pulse from a tunable dye laser, $\lambda=700$nm, pulse energy $\approx 2-10\mu J$. 1000V is applied across coplanar electrodes, 2mm apart. Shown here is the photocurrent at the specified time delay after the exciting laser pulse, normalized to the pulse energy. As the temperature gets below 200K, the slope becomes significantly steeper than $1-T/T_0$.

which is rapidly decreasing, most of the carriers will be at $E_d$. Most of the carriers in shallow states are at $E_d$ (for $T<T_0$) because of the Boltzmann factor. Most of the deep states are at $E_d$ because their number follows the DOS. Thus there is a packet of carriers, localized in energy, which moves through the DOS according to $E_d=kTn(Vt)$. The current is proportional to the number of carriers in transport states, $n(t)$. This is just the number of carriers (almost all of them) at $E_d$, multiplied by the appropriate Boltzmann factor and a degeneracy factor, $\propto N_c/g(E_d)$. Thus $n(t)\propto\exp(-E_d/kT)/g(E_d)$. For our exponential DOS, this gives $i(t)\propto t^{-1+\alpha}$, where $\alpha=T/T_0$. This simple picture was confirmed by PC measurements for $T>200$K which gave excellent agreement with the predicted slope of the log $i$ versus log $t$ plot, as a function of temperature. We are presently trying to find the source of the apparent discrepancy between this result and the TOF results, which were interpreted as having a temperature independent slope.

These high temperature PC measurements give the DOS at energies $kTn(Vt)$ from about .35 to .6eV from the edge. (This is the density of hole traps, since TOF measurements show that electrons are immobile in a-As$_2$Se$_3$.) To extend the DOS determination to lower energies we replaced the load resistor with a more elegant current to voltage converter to increase sensitivity and made measurements below 200K. The data, shown in Figure 1, deviate significantly from the $a-T/T_0$ behavior. The curves are noticeably steeper (more dispersive) than one would predict from the simple theory. At 77K the curves are even steeper and may have a slope near -2, but the data are too noisy to know, or even to plot on the figure. The deviation from previous behavior is shown most dramatically in Figure 2. Tiedje has seen similar results for a-Si:H as the temperature is lowered, with $\alpha$ going to zero at roughly 90K.
FIGURE 2. Slope of the log $i$ versus log $t$ plot of the photocurrent, treated as a power law, as a function of sample temperature. Data down to 200K show excellent agreement with a slope $-(1-\alpha)$, with $\alpha=T/T_0$. The 77K data could not be fit without throwing out many noisy points, and is therefore prejudiced.

There are two ways to understand these results. The first possible explanation is that the model is complete as stated, but the simple functional dependencies on energy could be different closer than .3eV to the edge. This means that either (1) the DOS is becoming flat or even developing a gap near the edge, or (2) the excitation prefactor $v_0(E)$ is varying in some exponentially rapid fashion, presumably due to an energy dependent barrier to trapping. Either of these would reflect interesting changes in the states near the mobility edge, for example, changes due to the much stronger electron phonon coupling of localized states. The other possible explanation is that a new conduction process is becoming important. The obvious possibility here is hopping directly between localized states. Certainly, at very low temperatures, no carriers would be excited to the transport states, and all current must be due to hopping. Before hopping becomes the principal mode of conduction however, it may still be visible by its effect on the thermalization of carriers, although the current is still dominated by carriers excited to the edge. A single carrier excited to the edge can generate much more current than a single hop. If this thermalization due to hopping occurs faster than that due to excitation to the band, the demarcation energy will shift faster than predicted, and the current will fall faster as well. An alternate thermalization was already suggested by the shift of the photoinduced absorption spectrum at 20K. At high temperatures, the transient PA spectrum shifts to higher (deeper) energies like $kT\ln(\nu_0 t)$ as the carrier packet thermalizes, but at 20K the shift, while smaller than at high temperatures, is greater than the $kT\ln(\nu_0 t)$ shift predicted from the MT model.

At present the low temperature data is not good enough to allow us to distinguish between these two possibilities, either one of which would be quite interesting. Whatever the answer to this new puzzle, however, the simple, physical insight provided by the MT model is sufficient to explain all of the higher temperature data. It has also been successfully used to understand recombination, as well as the TOF transit time, in a simple physical way.
REFERENCES

8. Orenstein, J. and Marc Kastner, to be published.