A Percolative Approach to Transport and Noise in Polyacenes

C. Pennetta, [1] and M. Tizzoni [2] and A. Carbone [2] and L. Reggiani [3]

[1]Dipartimento di Fisica, Università del Salento, Lecce, Italy

[2]Dipartimento di Fisica, Politecnico di Torino, Torino, Italy

[3]Dipartimento di Ingegneria dell'Innovazione, Università del Salento, Lecce, Italy

Recent transport measurements in polyacene organic semiconductors [1] have evidenced a strong superlinear increase of the current voltage (I-V) characteristic and a concomitant peak of the relative spectral density of current noise at voltages corresponding to the crossover between Ohmic and space charge limited currents (SCLC) regimes [2,3]. The interpretation of these experiments was addressed in terms of a continuous percolation model between the two asymptotic regimes (Ohmic and SCLC), considered as different conducting phases [2]. The noise increase was then attributed to the clustering of insulating regions among which current paths are constrained, thus leading to a substantial increase of the noise [2]. Very recently, we have proposed a complementary interpretation of these experimental findings, in terms of noise due to trapping and detrapping (TD) processes of injected carriers by deep traps in the trap filling transition (TFT) regime [4]. This interpretation was based on a phenomenological model which makes use of the measured $I-V$ characteristic to estimate the fraction of filled traps as a function of the applied voltage. Then, the last quantity is used to express the spectral density of current noise in the TFT regime. The good agreement between the behaviors obtained from the phenomenological model and the experiments supports the idea of abscribing the sharp peak of noise in the TFT region to the fluctuating occupancy of the traps due to TD processes. To further check this interpretation we have developed a new percolation model shortly discussed here together with its results. Further details can be found in [7,8]

The model is based on the well known resistor network approach [5,6] and it describes the semiconducting film as a binary and two-dimensional square-lattice resistors network (size $N \times N$). In the new model that we adopt here, each elementary resistor $r_{i,j}$ is subjected to random transitions from two states of resistances r_1 and r_2, with probabilities:

$$W_{1\to 2} = \exp\left[-(E_2 - qv_{i,j})/k_B T\right] \tag{1}$$

and:

$$W_{2\to 1} = \exp\left[-E_1/k_B T\right] \tag{2}$$

where $v_{i,j}$ is the voltage applied to $r_{i,j}$, E_1, E_2 are two activation energies and q is an effective charge. We assume these expressions of the transition probabilities from the two resistor states to mimic the effect of TD processs in the TFT region. It should be noted that the relative current noise of the network depends only on its size N and on the three ratios: $f_r = r_1/r_2$, $a = (E_2 - E_1)/K_B T$ and $b = q/K_B T$. The network evolution is calculated by numerical simulations and assuming constant-voltage boundary conditions. We take the following values for the model parameters: $N = 75$, $f_r = 290$, $a = 2.5$ and $b = 210 V^{-1}$. Figures 1 and 2 report the experimental behavior of the $I-V$ curve (red squares in Fig. 1) and of the relative spectral density of current noise at 20 Hz (red circles in Fig. 2), measured on a tetracene sample at 300 K [2]. The same figures show the corresponding curves obtained from the numerical simulations. Further details of the model, its results and limits will be discussed at the conference. In any case we consider satisfactory the agreement between experiments and model predictions.

In conclusion, we have considered the $I-V$ characteristic curve and the sharp peak of the relative spectral density of current noise observed as a function of the applied voltage in polyacene semiconductors [2]. A qualitative explanation of these findings was initially proposed in terms of continuous percolation between a Ohmic phase and an insulating SCLC phase. Recently [4], we have advanced another alternative interpretation of this behavior, based on a phenomenological model, in terms of trapping and detrapping (TD) processes of the injected carriers. To check these two alternative explanations, we have developed a new percolation model. The results of our numerical simulations [7,8] definitely support the conclusions of the phenomenological model.

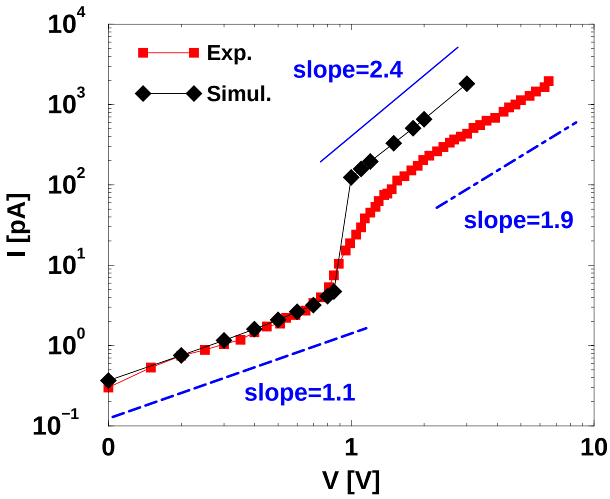

Figure 1. Red squares: experimental $I - V$ characteristic curve measured on a tetracene sample (Ref.). Black diamonds: $I - V$ characteristic obtained from numerical simulations based on the model described in the text.

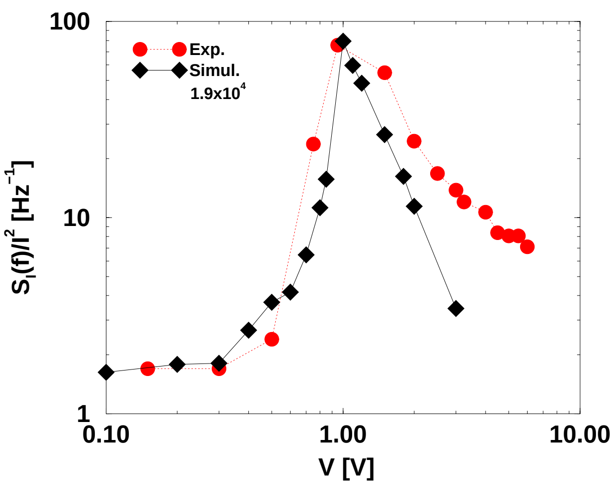

Figure 2. Red circles: experimental values of $S(f)$ (ref.). Black diamonds: relative current noise S_{sim} obtained from numerical simulations. The simulated values are normalized by a factor $S_{norm} = 5.26 \times 10^{-5}$ to agree with the measured value of S_{max}.

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