Mobility Enhancement of Electroluminescent Polymer Aggregates and Films Investigated by Conducting Atomic Force Microscopy

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We report the observation of mobility enhancement of electroluminescent polymer aggregates in as-prepared films and films after electrical annealing by conducting atomic force microscopy (CAFM). With the use of gold-coated AFM tips, local current-voltage curves were measured directly on isolated aggregates and films. The mobility was then determined with space charge limited current (SCLC) theory, and its relationship with the electric field was analyzed by Poole-Frenkel (P-F) law. On nanoscale aggregates in as prepared-films, the zero-field mobility was found to be 3 orders of magnitude higher than reported macroscopic results, but the field coefficient was in reasonable agreement. On films with a thickness of 25 nm, electrical annealing was performed by repeated scanning on a surface area. It was found that the local current increased by 10 times after 3 repeat scans, whereas no change in surface topography was noticed. The observed mobility enhancement is an indication of the stronger inter-chain interaction in the samples compared to as-prepared films.

Introduction

All polymer based devices are unequaled for their low cost. But the performance as an active layer of transistor still has a lot of problem needed to be overcome, such as low carrier mobility, interfacial influences and morphological effect.

To solve these problems, people try to understand the basic mechanisms of carrier transport in conducting polymers: P. W. M. Blom's group uses space charge limited current (SCLC) theory along with Poole-Frenkel (P-F) law to describe the relation between electric field and mobility[1-5]; E. M. Conwell's group uses Monte Carlo method to simulate carrier transport behavior in polymer chains[6].

Besides, B.J. Schwartz used scanning near-field field microscopy (SNOM) to investigate the nanoscale morphological influences on optical characteristics[7-12].

In this report, we use CAFM to investigate the nanoscale morphological influences on electric property. The results we obtained are consistent with the B.J. Schwartz's experiment and E. M. Conwell's simulations.

Results and Conclusion

The topography and current images of the MEH-PPV film obtained with a tip bias of +4V are shown in Fig. 1. Local I-V curves on three locations marked A, B, and C in Fig. 1 are shown in Fig. 2. With the use of SCLC theory and P-F law, the I-V curves are transformed into P-F plots. The parameters used for calculations are: the contact diameter is estimated to be 20 nm, and the relative dielectric constant is 3, and the thickness we used is 25 nm for the sample and 10 nm for the bump height.

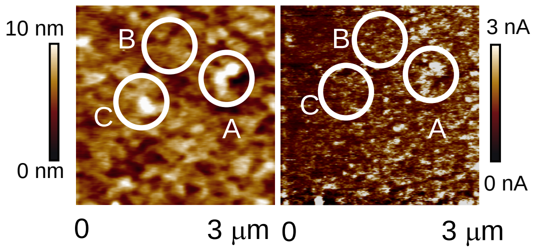

Fig. 1. The topography (left) and current (right) images of the MEH-PPV film. The tip bias is +4V.

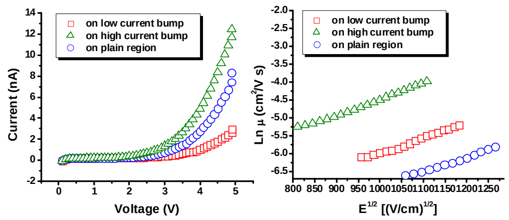

Fig. 2. I-V curves and P-F plots of selected region in Fig.1.

Furthermore, we analyzed the electric field coefficients and zero-field mobility as Table I. According to E. M. Conwell's simulation, it is found that the electric field coefficient E_0 will not be affected when the energy deviation of hopping sites is varied. Nevertheless, the zero-field mobility is largely dependent on the deviation.

Table I. Comparison chart of μ_0, E_0 and thickness on different positions

	A	B	C
μ_0 (10^{-5} cm^2/V.s)	13.5	2.13	3.84
E_0 (10^4 V/cm)	5.10	6.61	5.70
L (nm)	35	25	35

Since we use the same material, MEH-PPV, and upon the same ambient condition, of course we get the same E_0 with the macroscopic measurement results as 8.7×10^4 V/cm. And the μ_0 of the plain region is in agreement with H. N. Lin's report[13]. For the μ_0 enhancement of plain region may be due to nanoscale confinement or littler energy deviation between the sites which lower the difficulty of carrier conduction.

Furthermore, B. J. Schwartz used SNOM to do PL measurement on the bump and find that some bumps have a red-shift spectrum. This is due to the elongation of conjugation length. Thus, we find some bumps have high mobility should be owing to the elongation of conjugation length and this makes carries more easily to transport.

In addition, In order to check the electrical annealing effect, and directly to see how it affect the carrier mobility of polymer, we use CAFM with +2.5 V tip bias repeating scanning on the MEH-PPV in 5×5 μm^2 area several times and synchronously acquire the topography and current images as Fig.3. And the statistics are shown in Fig. 4 and Tab. II.

From Fig. 4, the height statistics are the same while the standard deviations of the current statistic are getting smaller with the times of repeat scanning increasing. This can be attributed to the extent of inter-chain interaction increased.

To check the difference between before and after annealing, we scanned a larger area further. According to the fig. 5, the region annealed could be clearly distinguished from un-annealed region. Furthermore, we go on scanning on the same region, and find the difference is getting slighter.

This result indicates a significant verification that as we apply bias voltage to anneal the quasi-stable polymer. The aggregates which can be imagined as entangled yards will penetrate to each other with their polymer chains and thus form a carrier high way network.

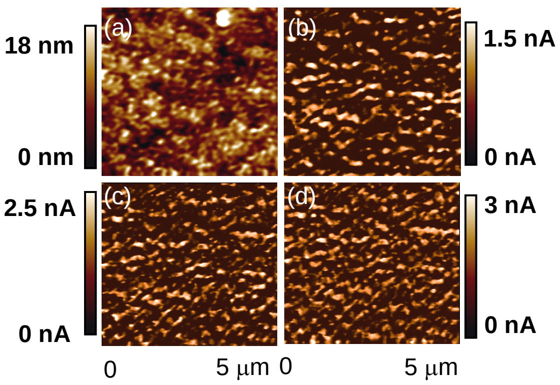

Fig. 3. With +2.5 V repeat scanning on the 5×5 μm² area. The topography image (a) and the current images of first time scanning (b) the second time scanning (c) the third time scanning (d).

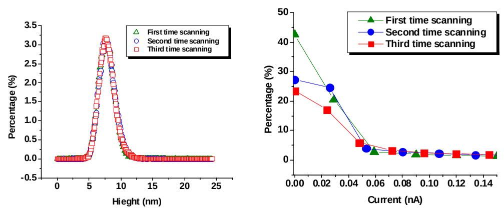

Fig. 4. Topography (left) and current (right) statistics of repeating bias with +2.5 V on 5×5 μm² area.

Table II. The standard deviation of current statistics of Fig. 4.

	1st time	2nd time	3rd time
R_{rms}	0.914	0.763	0.728

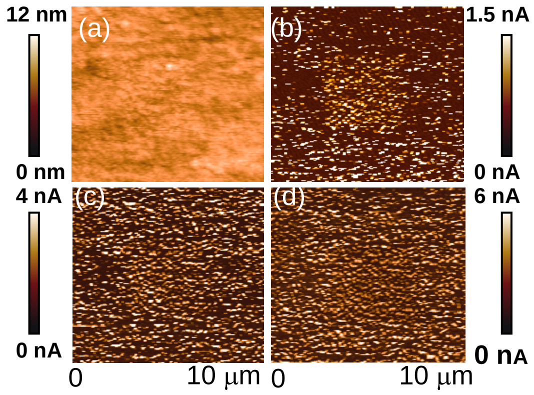

Fig. 5. With +2.5 V repeat scanning on the 10×10 μm² area. The topography image (a) and the current images of first time scanning (b) the second time scanning (c) the third time scanning (d).

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