Conductive Polymer and Semiconducting Quantum Dots Nanocomposite Systems

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INTRODUCTION

Conductive polymers have been considered as a novel class of electronic materials. The advantages of them including tunable conductivity, low cost and flexibility have stimulated a lot of interest in the fields of electronic and optoelectronic devices [1]. With the advent of better design and fabrication technology a wide selection of conductive polymers is available for applications in optoelectronic devices. High performance LEDs, solar cells, lasers and transistors have been developed with the conductive polymers.

STRUCTURE MODELLED

The composite structure is fabricated by mixing the polymer and the quantum dot solutions and spin casting a layer on an indium tin oxide (ITO) coated glass substrate. A schematic diagram of such a fabricated device is displayed in Fig. 1. The total thickness of the composite structure is approximately 1 micron. The weight to volume (w/v) ratio of the MEH-PPV (P3HT) solution in chloroform is 10 mg/ml. The CdSe dot solution is made in chloroform with a w/v ratio of 1 mg/ml [2]. The concentration of CdSe dots in chloroform is 10^{17} cm^{-3}. The top contact of MEH-PPV/CdSe system is made of gold (Au) pixels while the top contact of the P3HT/CdSe system is made of silver (Ag) pixels.

THEORY

We know that charge transfer from polymer to quantum dots is energetically favorable if the following condition is satisfied:

EA_{QD}-EA_{POL} > U_{POL}-V_{CT}

where EA_{QD} and EA_{POL} are the electron affinities for the quantum dot and the polymer, U_{POL} is the coulombic binding energy of the photo-generated exciton in the polymer and V_{CT} is the Coulombic attraction between the separated electron and hole. This is consistent with the observed quenching of the PL peaks from the polymers. Quenching of the polymer PL is shown in Fig. 2 which indicates charge transport from polymer to QDs.

The model used to simulate I-V curves is that of a double barrier quantum well device (DBQWD). The DBQWD consists of a quantum dot sandwiched between polymer molecules.

The device characteristics of this system are analyzed theoretically in terms of its resonant tunneling current. A transfer matrix method [3] was used to solve the transmission coefficient of electrons tunneling across the structure and the tunneling current is calculated using the Tsu-Esaki equation [4-5]

$$J = \frac{em^* kT}{2\pi^2\hbar^3}\int_0^\infty T(E)\ln\left(\frac{1+\exp\left[\left(E_f - E\right)/kT\right]}{1+\exp\left[\left(E_f - E - eV\right)/kT\right]}\right)dE$$

where m^* is the electron effective mass in the emitter, k is the Boltzmann constant, $\hbar$ is the reduced Planck constant, T is temperature, E_f is the Fermi energy of the electron in the emitter, E is the electron energy along the tunneling direction and V is the applied bias. The results of the simulations are shown in Fig. 3 and experimental results are shown in Fig. 4.

CONCLUSION

Photoluminescence and current voltage results for two different nanocomposite systems are presented with the theory of the charge transfer between quantum dot and the polymer; we also compare the results of the simulation of the I-V curves of the system and the results of the experiments. Modeled and experimental results for I-V curves in MEH-PPV/CdSe and P3HT/CdSe exhibit common features.

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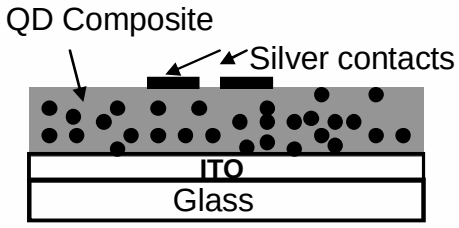

Fig. 1. Generic QD nanocomposite structure considered in this modeling effort.

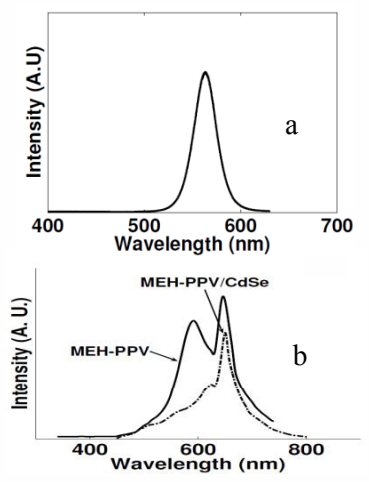

Fig. 2. (a) PL of CdSe (b) PL of MEH-PPV/CdSe sytstem comparing with PL of MEH-PPV. The EA values of CdSe QDs, MEH-PPV and P3HT is 3.7 eV, 2.8 eV and 3.2 eV. $U_{POL\text{-}MEH\text{-}PPV}$ is 0.2 eV and $U_{POL\text{-}P3HT}$ is 0.5 eV. Thus, electron transport is possible from MEH-PPV and P3HT to CdSe QDs. This is consistent with the observed quenching of the PL peaks from the polymers.

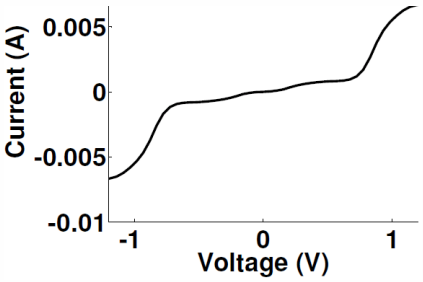

Fig. 3. I-V characteristics simulated on a single quantum dot between two metal electrodes; the case illustrated is for P3HT/CdSe DBQWD energy levels 0.13 eV and 0.45 eV. Extended results will be presented/

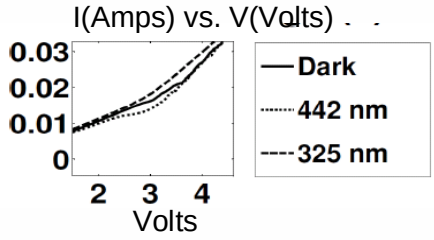

Fig. 4. I-V characteristics of MEH-PPV/CdSe system at room temperature.