Improving Efficiency of Solar Panels Using Music

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Abstract- Acoustic vibrations are used to improve the photovoltaic efficiency of a P3HT/ Zinc Oxide nanorod solar panel up to 45% which is correlated to a three-fold increase in charge carrier lifetime. This is assigned to the generation of piezoelectric dipoles in the ZnO nanorods, indicating that the efficiency of solar panel may be enhanced in the presence of ambient vibrations by the use of piezoelectric materials.

Keywords: solar cell, piezoelectric, hybrid, zinc oxide, P3HT.

I. INTRODUCTION

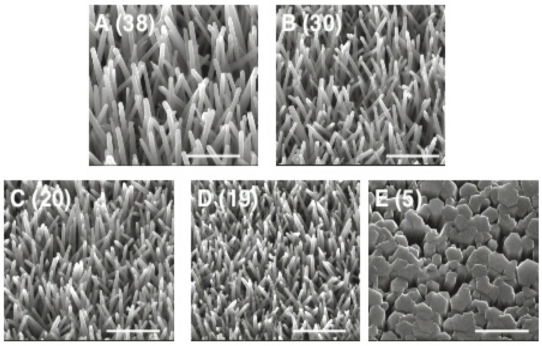
Photovoltaic (PV) devices based on conjugated polymers and nanostructure metal oxides have been widely studied as a hybrid inorganic/organic approach to solar energy conversion. A large source of loss in this type of device is non radiative recombination of the photogenerated charge carriers. Therefore, strategies to reduce this recombination have the potential to significantly increase device efficiency.If utilised effectively, the electric field generated by a non-centro symmetric crystal has the potential to modulate the performance of optoelectronic devices.

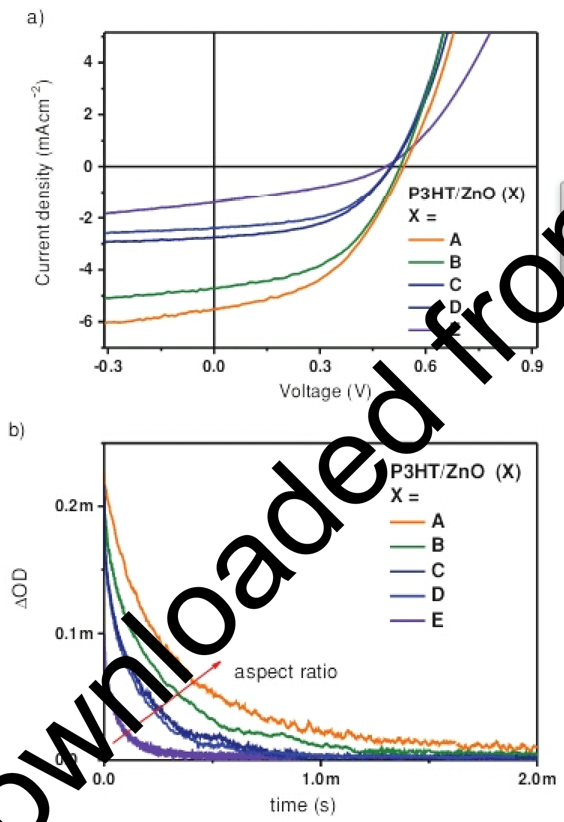
1.1Principle:

Piezoelectricity is the electric charge that accumulates in certain solid materials such as crystal in response to applied mechanical stress. The word *piezoelectricity* means electricity resulting from pressure. The piezoelectricity is the linear electromechanical interaction between the mechanical and the electrical state in crystalline materials with no inversion symmetry. The piezoelectric effect is a reversible process in the materials exhibiting the direct piezoelectric effect (the internal generation of electrical charge resulting from an applied mechanical force) also exhibit the reverse piezoelectric effect (the internal generation of a mechanical strain resulting from an applied electrical field).

II. REASON FOR SELECTING ZNO:

Nanostructured materials are currently attracting extensive attention to reduce the cost and/or enhance the efficiency of photovoltaic solar energy conversion. Such nanostructuring is typically employed to reduce the distance of the excited states or charge carriers must travel to reach a device interface. Hybrid structures of nanostructured metal oxides and conjugated polymers combine the structural control offered by the inorganic scaffold with the ease of processing and strong optical light absorption of semiconducting polymers. One of the most widely studied inorganic semi- conductors for such hybrid devices is zinc oxide it benefits from a wide band gap, good carrier mobility, a large variety of morphologies of particular interest for this manuscript, piezoelectric behaviour. A piezoelectric material produces a polarisation and associated electric field upon application of acoustic or mechanical stress, which can be employed to convert kinetic energy to electrical energy. If utilised effectively, this electric field has the potential to modulate the performance of optoelectronic devices. Control of the materials morphology and nanostructure is well known as a key determinant of device performance. For ZnO, there are many examples of different kinds of nano- structures that have been successfully characterized and integrated into optoelectronic devices nanoparticles, nanorods, nanotubes and nanoribbons being the most common. ZnO nanorods interfaced with the most widely used p-type polymer donor, poly 3-hexylthiophene (P3HT), provides a well-defined model system with which to study the impact of ZnO aspect ratio and external vibrations on photovoltaic device performance. It has previously been shown that in P3HT/ZnO nanorod array PVs, photocurrent improves with rod length. Other alternative ZnO PV's architectures have also demonstrated that there is an optimal length of nanorods and explained this is terms of carrier mobility and photon capture. In parallel to this nanostructured ZnO materials have been shown to exhibit a variety of vibrational energy harvesting capabilities. However piezoelectric effects to enhance the performance of photovoltaic devices have been very limited to date. Such studies have shown parallel piezoelectric and photovoltaic device performance where small piezoelectric voltage outputs are added to the photovoltage but lead to negligible enhancement in photovoltaic current generation and conversion efficiency under simulated solar irradiation (AM1.5 $\sim$1 00 mW cm $^{-2}$). No nanorods were grown on ZnO seeded conductive glass substrates using an aqueous chemical method. Five different sized nanorods were grown by varying the reactant concentrations and reaction time. The ZnO nanorods form homogeneous and well-oriented hexagonal shape with aspect ratios of A: 38, B:30, C:20, D:19, E:5, as shown in Figure 1. Aspect ratios were calculated by measuring the average length and diameter of the nanorods from cross-section SEM images . P3HT was deposited by a combined dip and spin coating methodology to yield efficient device performance. This method led to good penetration of the P3HT between the ZnO nanorods (Figure S2), leading to an intimate P3HT/ZnO layer with a thickness equal to the nanorod length and a capping layer of P3HT above the rods of 300–500 nm, which was kept constant by using a constant P3HT concentration and spin speed This prevented contact between the ZnO and the Au top electrode (which was evaporated to complete the device) by effectively acting as an electron blocking layer. In Figure 2 a current density-voltage (J-V) curves of ITO/ZnO seed layer/ZnO(X)/P3HT/Au devices, under A.M. 1.5 illumination, are shown for several different nanorod aspect ratios. It is apparent that increasing nanorod aspect ratio results in a significant enhancement in device performance. The highest photovoltaic power conversion efficiency is achieved with the highest aspect ratio (ZnO(A)), with a significant increase in the short-circuit current density (J_{sc}) and a slight increase in the open-circuit voltage (V_{oc}). An increase in J_{sc} as a function of rod length has recently been reported for analogous devices.This could partly be accounted for by the increased interface area of P3HT/ZnO(X), although the photocurrent correlated more closely with aspect ratio than interface area. Changes in V_{oc} may be partly accounted for by strain- induced band shifts. We note that, as typical of hybrid PV cells, the device fill factors were largely limited by dark shunt resistances.

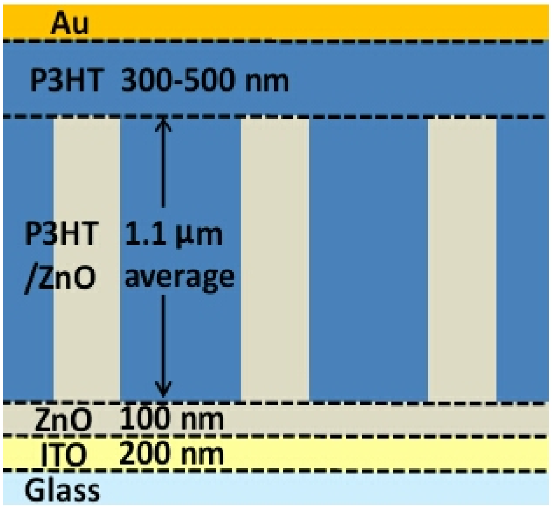




2.1 ZnO FabricationZnO

Nanorods were grown on ITO-coated glass substrates seeded with a sputtered ZnO fi lm. Seeded substrates were suspended in solutions of zinc nitrate and hexamethylenetetramine (HMT) and heated to 90 °C to grow the ZnO nanorods. Five different aspect ratios were produced by using different concentrations of reactants and different total reaction times. Depending on the reactant concentration the reactants became depleted after 2.5–4 hours after which the substrates were placed in a fresh solution. The following reactant concentrations, times and repeats were used for each type of rod: A, 25 m M HMT, 15 m M zinc nitrate, 8 repeats of 4 hours; B, 25 m M HMT and 15 m M zinc nitrate, 4 repeats of 4 hours; C, 25 m M HMT and zinc nitrate, 6 repeats of 2.5 hours; D, 25 m M HMT and zinc nitrate, 3 repeats of 2.5 hours; E, 0.1 M HMT and zinc nitrate, one 4 hour reaction. After growth the ZnO nanorods were annealed in air at 400 °C for 1 hour.

Scanning electron microscopy (SEM) images of ZnO nanorods were recorded using an FEI Inspect-F SFEG SEM.



2.2 Device Fabrication

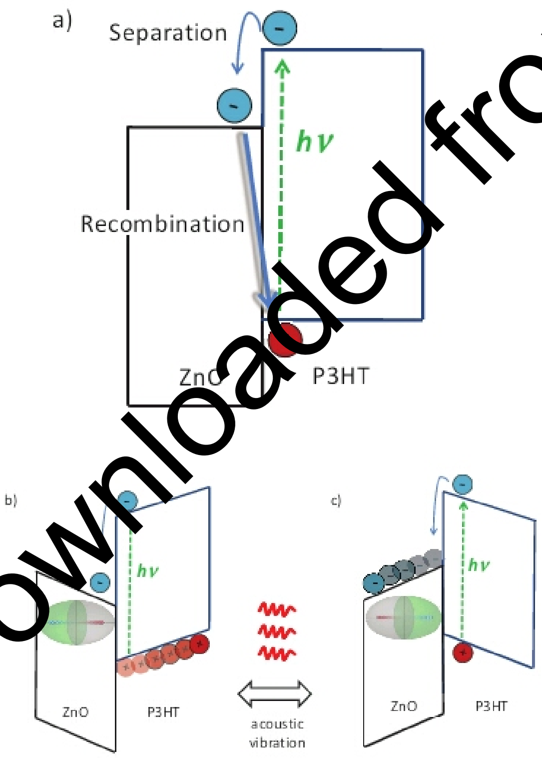
ZnO nanorod samples were fi rst immersed overnight in a solution of polymer in chlorobenzene (2 g/L). The dip coated fi lms were then dried by N 2 gas. Subsequently a polymer layer was spin coated from chlorobenzene (45 g/L) at 1100 rpm. Finally gold contacts (50 nm) were deposited by evaporation. Transient absorption decays were measured by exciting the sample fi lm under a nitrogen (and oxygen) atmosphere, excitation pulses were generated with a commercially available optical parametric oscillator (Oppolette) pumped by Nd:YAG laser (Lambda Photometrics). The excitation wavelength used was 500 nm for P3HT and 550 nm for PCDTBT blend fi lms, with a pump intensity of 0.4 – 20 µ J.cm −2 and a repetition frequency of 20 Hz. For 1 µ s – 1 ms timescale, a 100 W quartz halogen lamp (Bentham, IL 1) with a stabilised power supply (Bentham, 605) was used as a probe light source (980 nm). The signal from the photodiode was pre-amplifi ed and sent to the main amplifi cation system with an electronic band-pass filter (Costronics Electronics). The amplifi ed signal was collected with a digital oscilloscope (Tektronics, TDS220), which was synchronised with a trigger signal of the pump laser pulse from a photodiode (Thorlabs Inc., DET210). To reduce stray light, scattered light and sample emission, two monochromators and appropriate optical cut-off fi lters were placed before and after the sample. For all devices, the external control vibration was applied at a fi xed distance, through a load speaker at 75 dB, with frequencies in the range 1–50 kHz.

2.3 Charge Carrier Recombination:

Transient absorption data were also measured under applied acoustic vibration. For all blends studied, this applied stress resulted in a substantial increase in the charge carrier lifetime. Typical data are shown in Figure 3 b for the highest aspect ratio rods (exhibiting the largest effect), which shows an increase in carrier lifetime from 0.34 ms to 0.88 ms under applied stress. Analogous data were obtained for PCDTBT/ZnO junctions whilst control data on P3HT:PCBM blend fi lms displayed no such depend- ence on applied stress. These data provide clear strong evidence that acoustic vibrations can substantially enhance the charge carrier lifetime in polymer/ZnO nanorod fi lms. The transient absorption data increases by up to 50% in initial signal amplitude both with increased nanorod aspect ratio and applied strain. This is indicative of either increased charge separation efficiency, or reduced recombination losses on timescales faster than our time resolution (~ 100 ns). In order to investigate this issue fur- ther, photoluminescence data were collected to assay the extent of P3HT emission quenching relative to a neat P3HT fi lm For all the P3HT/ZnO film P3HT emission was observed to be strongly quenched, with the quenching efficiency increasing modestly with decreasing aspect ratio from ~9 0 to 98%. These data suggest that neither variation in P3HT exciton diffusion nor exciton separation at the P3HT/ ZnO interface are likely to strongly impact upon the trends in charge carrier yields and photocurrent densities we report. As such, we assign the increased photovoltaic device performances with both aspect ratio and acoustic strain that we observe herein to reduced losses due to charge carrier recombination (non-geminate and potentially geminate), as indicated by the transient absorption data . Our transient absorption data indicate that the observed increases in charge carrier signal amplitudes and lifetimes (50% and three- fold increases respectively) are large enough to explain the increases in photovoltaic device efficiency with nanorod aspect ratio and acoustic strain . The possible mechanisms within our model PV system that could be affected by the nanorod aspect ratio and acoustic vibration leading to enhanced carrier lifetime and device performance. There are a number of effects that can result from subjecting the devices to acoustic vibrations. It is possible that the applied vibration and additional freedom of movement could improve the interfacial contact between the ZnO and P3HT leading to increased device effi ciency. However, this would be expected to increase P3HT exciton quenching rather than retard recombination, in direct contrast to our transient absorption and photoluminescence quenching data.

2.3 Voltge Drop

Additionally, the acoustic vibrations could induce local heating in the materials. However, local heating would be expected to accelerate recombination losses and reduce cell voltage, again in contrast to our experimental observations. Furthermore, the acoustic vibration induced performance enhancement we report is fully reversible, indicating the acoustic vibrations do not result in any irreversible change in materials structure. Our comparison of three different junctions: P3HT/ZnO, PCDTBT/ ZnO and P3HT:PCBM clearly indicates that observed PV efficiency enhancement under acoustic strain originates from the ZnO nanorods and specifically their mechanical response to both ambient and applied vibrations. Additionally, the enhancement does not occur in P3HT:PCBM/ZnO films, where the charge separation and recombination interface is between the P3HT and PCBM, not at the ZnO interface. Thus the enhancement only occurs in configurations where the charge separation interface is at the ZnO surface, which implies that the effect results form a change in the properties of this interface brought about by the acoustic vibrations. As ZnO is a piezoelectric material and therefore develops a polarisation and associated surface charge upon the application of external stress. We have shown previously that a ZnO nanorod-polymer system can develop an external voltage due to the piezoelectric effect when subjected to acoustic vibra- tion, which increased with applied frequency and the aspect ratio or length of the rods. The direct piezoelectric power output from the devices when subjected to external vibration in the dark was much smaller than the vibration-induced increase in solar to electric power output observed under solar irradiation, indicating that this increase cannot be a simple additive effect. Therefore the enhanced photovoltaic Dc performance reported herein originates from the impact of piezoelectrically-induced electric fields on the charge photogeneration and recombination dynamics of the device. The mechanism by which the piezo electric polarisation could enhance the lifetimes of photogenerated charge carriers in the hybrid polymer/ZnO nanorod devices and thereby increase device solar to electric power conversion efficiency. when ZnO nanorods experience strain due to vibrations, an alternating polarisation will develop across these nanorods. The electric fields associated with this polarisation can be expected to extend into both the ZnO and polymer components. Such fields in piezo and ferroelectric are well-known to strongly influence free carriers at the interface, which leads to screening of the polarisation as the carriers rearrange. As the nanorods vibrate, the surface will fl uctuate between positive and nega- tive polarisations. These polarisations will provide an oscillating modulation of the energetics of exciton separa- tion at the P3HT/ZnO interface. As this effect should alternate between a positive and negative contribution, and is in any case likely to be small compared to the large energy offset driving exciton separation (~ 1 eV), it is unlikely to be the origin of observed performance enhancement. This is in agreement with our spectroscopic data which indicates that the performance enhancement does not derive from increased exciton separa- tion. However, after excitation separation, depending upon the polarity of the ZnO polarisation relative to the polymer/ZnO excitation separation. We note the inversion of field orientation with acoustic oscillations would result in oscillating enhancement and suppression of exciton separation, likely to cancel out even if this is significant effect. A comparable model can used to explain the enhancement of device performance with nanorod aspect ratio even in the absence of applied acoustic strain – the higher aspect ratio rods can be expected to bend to a greater degree under the ambient vibrations, increasing piezoelectric polarisation and thus retarding recombination losses, consistent and other effects may also contribute to the reported efficiency enhancements. The good qualitative agreement with our transient kinetic and device data, and illustrates the potential for oscillating piezoelectric effects to enhance photovoltaic device performance. On a lighter note, the response of the devices to a variety of acoustic conditions was investigated by playing a variety of different types of music during testing, rather than single frequency signals as used above.



III. EFFICIENCY

It was found that the efficiency enhancement was most pronounced for pop rather than classical music, most probably due to the increased amplitudes of higher frequencies typically present in electronically synthesized music. The solar to electric power conversion efficiency of P3HT/ZnO hybrid solar cells can be substantially enhanced both by increasing ZnO nano rod aspect ratio and the application of modest acoustic vibration. This enhancement has been shown using transient absorption studies to originate from reduced charge carrier recombination losses, which have been explained via the piezoelectric effect in the ZnO nanorods

CONCLUSION

The proposed model is consistent with the lack of enhancement in control systems. We envisage these effects may also be relevant to other photovoltaic device structures which employ high aspect ratio nanostructures capable of piezoelectric effects. This conclusion is supported by the analogous results for the PCDTBT/ZnO system. This discovery may lead to applications where photovoltaic, as well as other opto electronic devices such as sensors, could be sited in areas of high ambient vibrations such as on air-conditioning units on roofs, on vehicles or in enhancement.

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