# Zinc Oxide Based Ultraviolet Solar Cells for Self-Powered Smart Window Application

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## Abstract:

A controlled study was completed in order to determine the best structure for a zinc oxide (ZnO) based solar cell that could be used to drive an electrochromic stack. Gold (Au), aluminum (Al), silver (Ag), and the organic polymer poly(3,4-ethylenedioxythiophene) poly(styrenesulfonate), or PEDOT:PSS, were used as top contacts for the device with the aim of creating a Schottky barrier junction with ZnO. The devices were fabricated on both silicon (Si) and indium tin oxide (ITO) substrates. The most effective solar cell structure showed an open circuit voltage ($V_{oc}$) of 1.90 V and a short circuit current density ($J_{sc}$) of 0.180 $\mu$A/cm$^2$. However, the device had an ideality factor of 1.66 and an efficiency of 0.057%, indicating that several loss mechanisms are hindering its performance.

## Introduction:

Integrating electrochromic films into existing business and residential windows has been proposed as a way of reducing building power consumption by cooling it in a passive manner. A voltage can be applied to the electrochromic stack, thereby increasing its opacity and blocking the solar infrared and ultraviolet radiation from entering the structure and heating the interior. ZnO based solar cells are promising candidates for supplying such a voltage, as ZnO possesses a wide bandgap, is visibly transparent in thin film microstructures, and forms a large Schottky barrier with a variety of metals and organic compounds, including Au (0.71 eV) [1], Ag (0.69 eV) [2], and PEDOT:PSS (0.9 eV) [3].

In theory, a device containing a ZnO-metal Schottky diode is capable of driving an electrochromic stack.

## Experimental Procedure:

The solar cells to be investigated were fabricated using highly-doped Si (20 mΩ/cm) and ITO coated glass substrates that were sputtered with 1 $\mu$m of ZnO. All of the devices were then treated with an oxygen plasma for fifteen minutes to clean the surface and to increase its hydrophilic nature. PEDOT:PSS was then dynamically spun onto half of the devices at 5000 rpm for 60 s and then annealed on a hot plate in air at 160°C for five minutes. Gold and aluminum top contacts were evaporated onto all of the devices using a shadow mask. Conductive silver paint was also applied to the devices as an inexpensive alternative to evaporated silver contacts. A device schematic is shown in Figure 1.

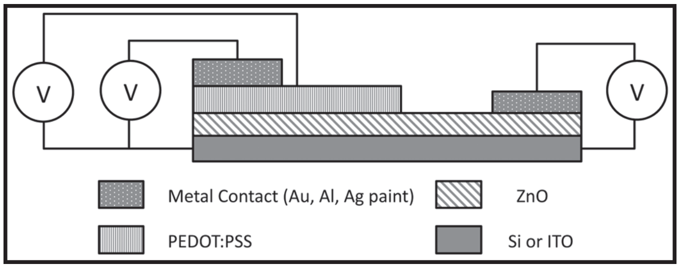


*Figure 1: Schematic of a complete solar cell, showing all of the contact configurations that were used.*

To characterize the performance of the solar cells, the current-voltage characteristics of each were measured under dark conditions as well as under a halogen white light lamp and a 365 nm ultraviolet lamp.

## Results and Conclusions:

The current-voltage (I-V) measurements of the devices proved to be inconsistent, and not all devices exhibited a photovoltaic response. Of the devices that did show a photovoltaic response, the best performance came from one with a Au/PEDOT : PSS/ZnO/Si structure, exhibiting a $V_{oc}$ of 1.90 V and a $J_{sc}$ of 0.180 $\mu$A/cm$^2$. The I-V characteristics and dark current density plot for this device are shown in Figure 2 and Figure 3, respectively. However, the device possessed an ideality factor of 1.66 and an efficiency of just 0.057% and did not exhibit diodic behavior. The devices that did not show a photovoltaic

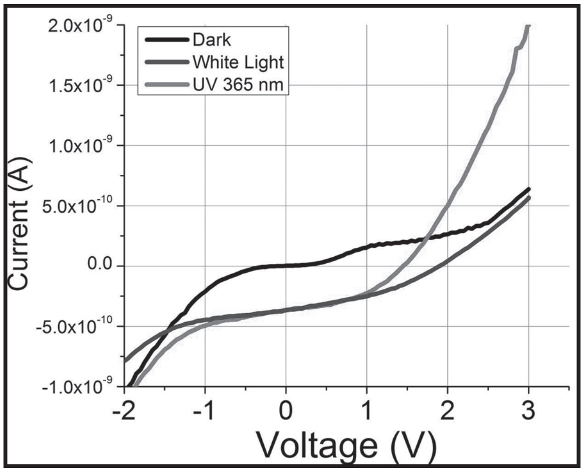


*Figure 2: I-V characteristics of the Au/PEDOT:PSS/ZnO/Si device. The offset between the dark and illuminated currents indicates a photovoltaic response. However, the curve does not resemble that of a diode.*

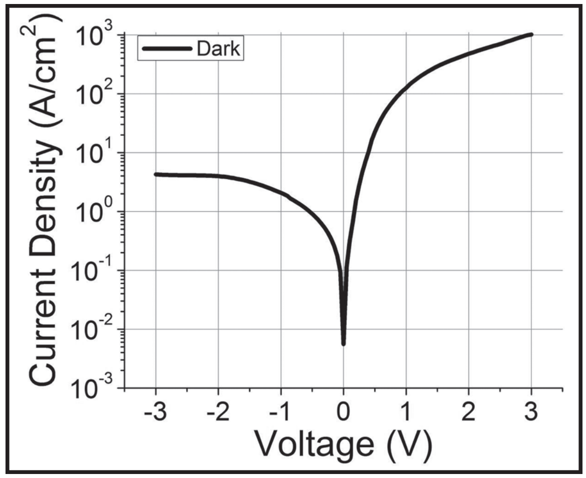


*Figure 3: Dark current density plot for the Au/PEDOT:PSS/ZnO/Si device.*

response demonstrated consistent rectifying behavior with Au contacts, but the Al and Ag contacts only showed occasional rectifying behavior. None of the PEDOT:PSS contacts showed rectifying behavior.

It is also of note that none of the devices that showed a photovoltaic response also showed rectifying behavior; conversely, the devices that showed rectifying behavior did not show a photovoltaic response. This is likely due to the presence of several loss mechanisms within the devices, including spontaneous polarization, oxygen deficient surfaces, grain boundaries, and recombination at the surface and back contacts. It is believed that recombination is the most significant of these mechanisms.

## Future Work:

Deep-level transient spectroscopy must be used to measure the electrical defects so that they can be targeted and mitigated. If recombination is determined to be a major factor in the compromised performance in the solar cells, an electron blocking layer could be introduced to inhibit the process. The $V_{oc}$ and $J_{sc}$, and efficiency of the devices could also be improved by treating the PEDOT:PSS layer so as to enhance its conductivity. Xia et al. has proposed that dilute sulfuric acid treatments of PEDOT:PSS can enhance its conductivity to ~ 3000 S/cm [4]. P-type doping of the photoactive ZnO layer could also be explored, possibly enabling the use of a p-n junction rather than a Schottky barrier junction.


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