BAPVC Annual Project Report

Project Title: High efficiency CdTe/MgCdTe double heterostructure solar cells
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Summary:

The goal of this project is to demonstrate single-crystalline CdTe/MgCdTe double heterostructures (DH) and high efficiency solar cells on lattice-matched InSb substrates to better understand the systems material properties and device performance. The group has demonstrated a record-long minority carrier lifetime of 2.7 μs for CdTe/MgCdTe double heterostructures. In addition, the group demonstrated monocrystalline ZnTe/CdTe/MgCdTe double heterostructure solar cells with a maximum efficiency of 10.9 %, an open-circuit voltage (V_{OC}) of 759 mV, a short-circuit current density (J_{SC}) of 21.2 mA/cm^2 and a fill factor (FF) of 67.4 %.

Key Accomplishments:

High quality CdTe/MgCdTe double heterostructures (DH) are grown on lattice-matched InSb substrates using a dual chamber MBE system at ASU. The group has determined the interface recombination velocities for various CdTe/$Mg_xCd_{1-x}Te$ heterointerfaces with different Mg compositions. Fig.1 shows a significant reduction in the interface recombination velocity and Fig. 2 shows a greatly improved minority carrier lifetime. Using time-resolved photoluminescence, the interface recombination velocities for the CdTe/$Mg_{0.36}Cd_{0.64}Te$ and CdTe/$Mg_{0.46}Cd_{0.54}Te$ interfaces were found to be 66±17 cm/s and 47±20 cm/s, respectively. A record-long minority carrier lifetime of 2.7 μs is observed, showing the great potential of CdTe/MgCdTe double heterostructures in photovoltaic and other optoelectronic device applications. Experimental evidence indicates that single-crystalline CdTe is approaching the radiative-limited regime at room temperature. The recent results on high quality CdTe crystal growth on InSb and the critical role of CdTe surface recombination have already greatly helped First Solar to better understand their materials and device designs. This model material and resulting devices will help probe the fundamental physics of CdTe surfaces and interfaces, and eventually help improve the device performance of poly-crystalline CdTe cells at the manufacturing scale.

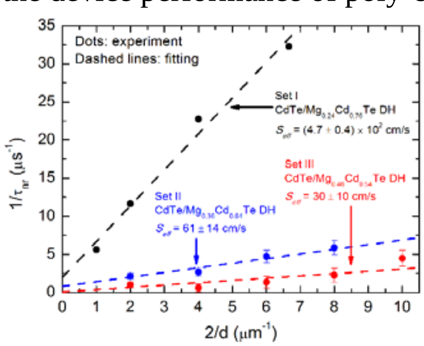

Fig. 1 Plots of $1/\tau_{nr}$ versus $2/d$ for CdTe/$Mg_{0.24}Cd_{0.76}Te$, CdTe/$Mg_{0.36}Cd_{0.64}Te$ and CdTe/$Mg_{0.46}Cd_{0.54}Te$ double heterostructures.

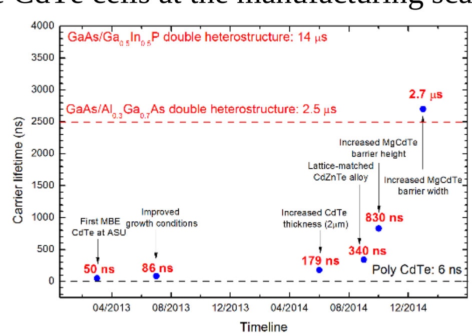

Fig. 2 The minority carrier lifetime progress of the CdTe/MgCdTe DHs.

The team designed and demonstrated monocrystalline p-ZnTe/p-CdTe/n-CdTe/n-MgCdTe double-heterostructure (DH) solar cells with a maximum efficiency of 10.9 %, an open-circuit voltage (V_{OC}) of 759 mV, a short-circuit current density (J_{SC}) of 21.2 mA/cm^2 and a fill factor (FF) of 67.4 %. The effective surface reflection from the hero sample is measured to be 7.7 % with 75 nm thick Al_2O_3 as the single layer AR coating, providing the light J-V curve and EQE curve in Fig. 3. The efficiency is lower than what simulations suggest mainly due to the combination of the low V_{OC} and FF, which are attributed to high interface recombination velocity at the p-CdTe/n-CdTe growth interruption interface. EQE and IQE measurements indicate low non-radiative recombination in the bulk CdTe region as well as at the CdTe/MgCdTe interface. However, a huge drop near, and above the ZnTe band gap is observed which can be attributed to absorption loss in the ZnTe layer, surface recombination loss and interface recombination loss at the p-ZnTe/p-CdTe and p-CdTe/n-CdTe interfaces. PC1D is used to fit several device variables to actual device performance. The results indicate that the surface recombination velocity is ~10^4 cm/s where the interface recombination velocity is ~10^5 cm/s at the p-ZnTe/p-CdTe or p-CdTe/n-CdTe interface.

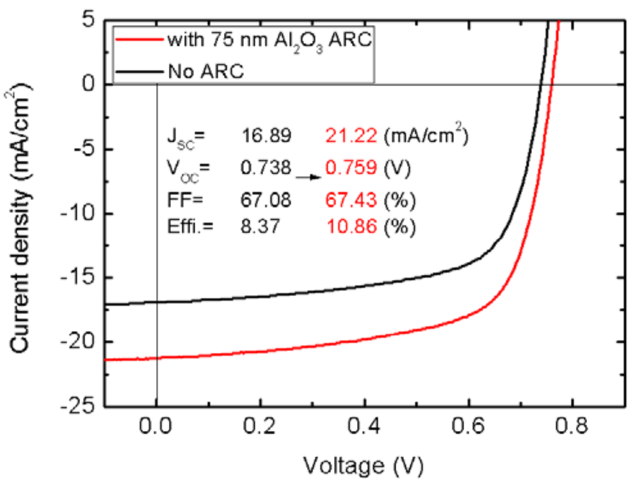

Fig. 3 (a) Light J-V curve of the ZnTe/CdTe/MgCdTe DH solar cell before and after ARC coating at room temperature under 1 sun illumination.

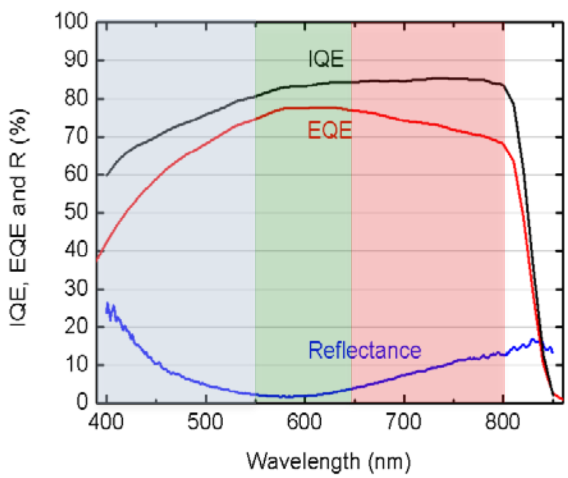

Fig. 3 (b) Measured EQE, reflectance, and IQE of the ZnTe/CdTe/MgCdTe DH solar cell under 1 sun illumination.

Future Work:

The group has identified two areas that are essential for the further improvement of the CdTe solar cells efficiency. The first is to successfully demonstrate p-type doping in CdTe, while the other is demonstration of higher V_{OC}. New device structure designs and p-type doping approaches are ongoing. Carrier transport across the CdTe/InSb hetrovalent interface will be investigated.