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P. R. Sharps
EMCORE Photovoltaics
10420 Research Road SE
Albuquerque, NM 87112
Phone: 505/332-5022
Fax: 505/332-5038
Paul_Sharps@emcore.com
Category 4B
Oral

AlGaAs/InGaAlP Tunnel Junctions for Multijunction Solar Cells

P. R. Sharps, N. Y. Li, J. S. Hills, and H. Hou
EMCORE Photovoltaics
10420 Research Road SE
Albuquerque, NM 87112

P. C. Chang and A. Baca
Sandia National Laboratory
Advanced Semiconductor Technology
P.O. Box 5800
Albuquerque, NM 87185-0603

Optimization of $GaInP_2$/GaAs dual and $GaInP_2$/GaAs/Ge triple junction cells, and development of future generation monolithic multi-junction cells will involve the development of suitable high bandgap tunnel junctions. There are three criteria that a tunnel junction must meet. First, the resistance of the junction must be kept low enough so that the series resistance of the overall device is not increased. For AM0, 1 sun operation, the tunnel junction resistance should be below 5×10^{-2} Ω–cm. Secondly, the peak current density for the tunnel junction must also be larger than the J_{sc} of the cell so that the tunnel junction I-V curve does not have a deleterious effect on the I-V curve of the multi-junction device. Finally, the tunnel junction must be optically transparent, i.e., there must be a minimum of optical absorption of photons that will be collected by the underlying subcells.

We have looked at four "high" bandgap tunnel junctions, $Al_{0.4}Ga_{0.6}As$:C/$In_{0.5}Ga_{0.5}P$:Si, $Al_{0.4}Ga_{0.6}As$:C/$In_{0.5}Ga_{0.4}Al_{0.1}P$:Te, $Al_{0.9}Ga_{0.1}As$:C/$In_{0.5}Ga_{0.3}Al_{0.2}P$:Si, and $Al_{0.9}Ga_{0.1}As$:C/$In_{0.5}Ga_{0.3}Al_{0.2}P$:Te. The bandgap of $Al_{0.9}Ga_{0.1}As$ and $Al_{0.4}Ga_{0.6}As$ are 2.1 eV and 1.9 eV, respectively, while the bandgap of $In_{0.5}Ga_{0.3}Al_{0.2}P$ and $In_{0.5}Ga_{0.4}Al_{0.1}P$ are 2.1 eV and 2.0 eV, respectively. Each active layer of the tunnel junction is 250Å thick, sandwiched by GaAs layers. All of the tunnel junctions were grown by metal-organic chemical vapor deposition (MOCVD), the growth method of choice for commercial production of III-V space solar cells. All of the devices have the p-on-n structure, and were processed as 100 μm x 100 μm diodes. The maximum electron density achieved for Si doping of both compositions of InGaAlP is 5×10^{18} cm^{-3}. With Te, an electron carrier density of 1.5×10^{19} cm^{-3} is achievable. Both

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compositions of AlGaAs are doped with C, with a maximum hole density of 1.5 x 10^{19} cm^{-3} being attained.

The I-V curves for the different tunnel junctions are shown in the Figures 1 through 4, along with the peak current and series resistance for each structure. Only the $Al_{0.9}Ga_{0.1}As$:C/$In_{0.5}Ga_{0.3}Al_{0.2}P$:Te tunnel junction meets the criteria mentioned previously, with J_p being 1,500 mA/cm^2, and R_s being 2.5 x 10^{-2} Ω–cm^2. While it is possible to degenerately dope $In_{0.5}Ga_{0.5}P$ with Si, the level is not high enough to reduce the series resistance to the values needed for a multijunction device. With $In_{0.5}Ga_{0.3}Al_{0.2}P$, however, degeneracy cannot be achieved with Si doping, as can be seen from Fig. 3. Compensation occurs before degeneracy is reached, with increased amounts of Si above a certain point reducing the n-type carrier density.

Because of concern about a Te memory effect, an iteration of the $In_{0.5}Ga_{0.3}Al_{0.2}P$:Te/$Al_{0.9}Ga_{0.1}As$:C tunnel junction was grown with reduced amounts of Te. Unfortunately, the series resistance of the junction is increased to an unacceptable level. The precise growth conditions have a significant effect on the final device results.

A SIMS analysis was done on the sample shown in Fig. 4, to determine how abrupt the doping profiles are, and to see any Te memory effect. The results indicate that within 0.1 µm the Te doping level drops to the background level. The Te memory effect is minimal, and should have no effect on a multijunction device that would use the $In_{0.5}Ga_{0.3}Al_{0.2}P$:Te/$Al_{0.9}Ga_{0.1}As$:C tunnel diode.

To our knowledge, the $Al_{0.9}Ga_{0.1}As$:C/$In_{0.5}Ga_{0.3}Al_{0.2}P$:Te tunnel junction is the highest bandgap tunnel junction made to date. The tunnel junction has the necessary optical and electrical properties such that it could be used in a AM0, 1-sun monolithic multijunction solar cell.

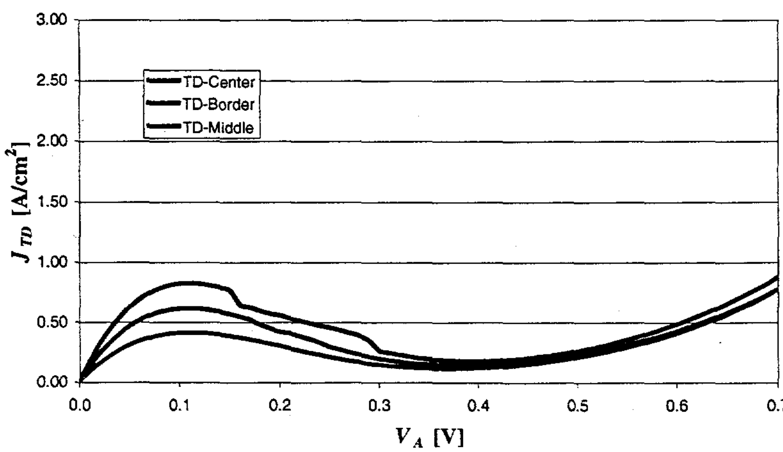

Figure 1. I-V curve for the $In_{0.5}Ga_{0.5}P$:Si/$Al_{0.4}Ga_{0.6}As$:C tunnel diode. The J_p is 600 mA/cm^2, and the R_s is 7.5 x 10^{-2} Ω–cm^2.

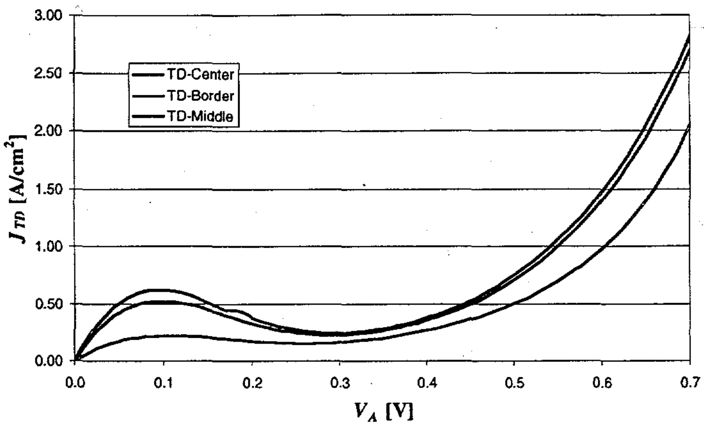

Figure 2. I-V curve for the $In_{0.5}Ga_{0.4}Al_{0.1}P$:Te/$Al_{0.4}Ga_{0.6}As$:C tunnel diode. The J_p is 500 mA/cm^2, and the R_s is 7.5 x 10^{-2} Ω–cm^2.

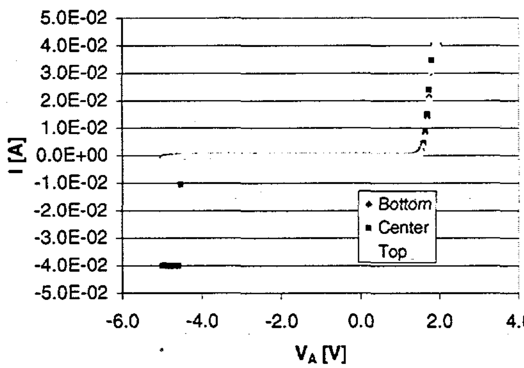

Figure 3. I-V curve for the $In_{0.5}Ga_{0.3}Al_{0.2}P$:Si/$Al_{0.9}Ga_{0.1}As$:C junction. No tunneling action is seen because the $In_{0.5}Ga_{0.3}Al_{0.2}P$:Si is not degenerate.

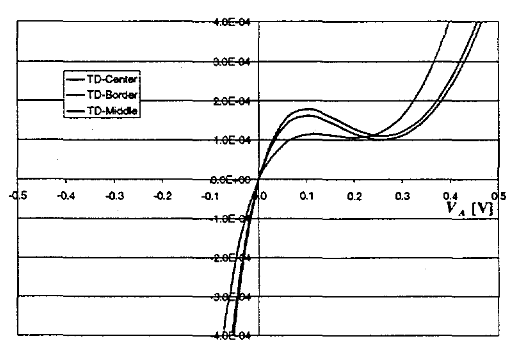

Figure 4. I-V curve for the $In_{0.5}Ga_{0.3}Al_{0.2}P$:Te/$Al_{0.9}Ga_{0.1}As$:C tunnel diode. The J_p is 1,500 mA/cm^2, and the R_s is 2.5 x 10^{-2} Ω–cm^2.