Exploring New Methods of Enhancing the Photovoltaic Effect of Ge/ GaAs Solar Cells

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Abstract

Thin film Ge/ GaAs solar cells were grown using an AJA ORION-8 Physical Vapor Deposition System. The ORION system is capable of both electron beam and magnetron sputtering deposition. Film crystallinity was characterized via reflective high energy electron diffraction (RHEED). An antireflective coating of MgO was implemented to reduce losses due to surface reflection. The absorption profile of the MgO coating was characterized via a Cary UV-Vis-NIR Spectrophotometer. The reflectance profiles of both the MgO coating and the Ge layer were measured using a Filmetrics F20 Interferometer. Poled ferroelectric nanoparticles of $BaTiO_3$ were utilized as a new method to enhance the electric field produced at the Ge/ GaAs junction. The I-V characteristics of the cells were tested using a Solar Light 16S solar simulator.

The Ge RHEED images showed evidence of epitaxial Ge growth. MgO was found to be optically transparent based on the absorption curve. The MgO AR coating reduced surface reflectance by 39% at a wavelength of 550 nm. MgO also generated a rectifying effect in the I-V curve. Poled BTO nanoparticles reduced dark current and increased light current, while also enhancing the rectifying effect in the I-V curve. Ge did not show any photovoltaic response.

Introduction

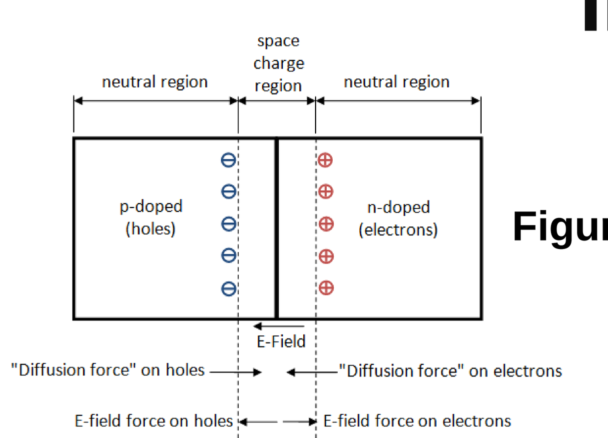


Figure 1. *Schematic of a p-n junction.*[1]

Properties of Si, GaAs, and Ge:

Material	Band Gap	Direct BG/ Indirect BG	Highest Interacting λ	Record Efficiency
Si	1.11 eV	Indirect BG	1118 nm	25%
GaAs	1.43 eV	Direct BG	868 nm	29.1%
Ge	0.66 eV	Indirect BG	1880 nm	40.4%

Table 1. *The record efficiencies were given for single-crystalline Si, single-crystalline GaAs, and a multi-junction Ge cell: GaInP/GaInAs/Ge/Si.*[2,3]

- •GaAs solar cells have found a niche in space applications.
  - relatively insensitive to heat[4]
  - •highly resistant to radiation damage[4]

Ferroelectric Layer:

•Ferroelectric materials exhibit a spontaneous polarization which can be reoriented by the application of an electric field.

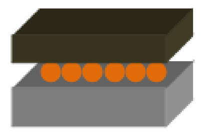


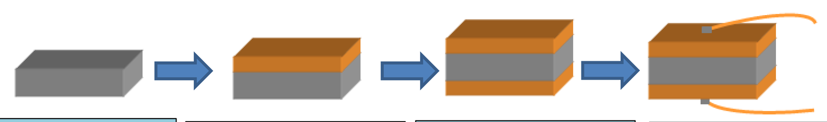
Figure 2. *In principle, adding BTO nanoparticles to the Ge/ GaAs interface should enhance the electric field already generated by the photovoltaic effect, increasing charge separation and cell efficiency as a result.*

Antireflective (AR) Coating:

- •An AR coating is used to reduce reflective losses at the surface.
- •MgO is an example of an AR coating.
  - •Band gap = 5.6 eV; index of refraction = 1.73; interacts with light up to 222 nm

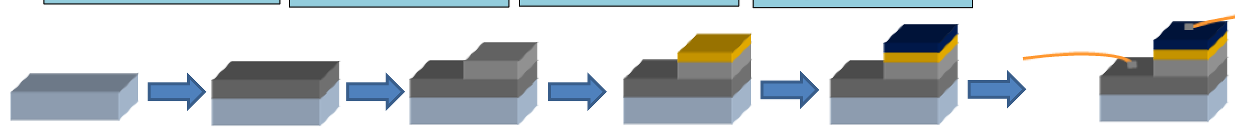
Solar Cell Fabrication

GaAs Solar Cell:



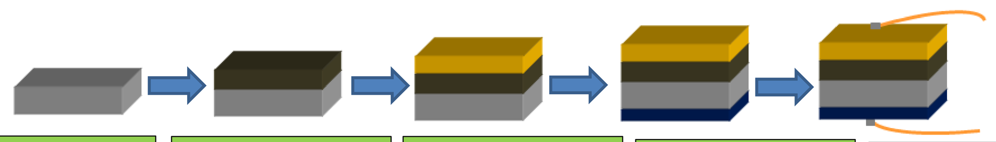
Sonicate & etch GaAs substrate.[5]	Deposit 20 nm Cu via sputtering.	Deposit 20 nm Cu via sputtering.	Attach Cu wire via Ag paste.

Ge Solar Cell:



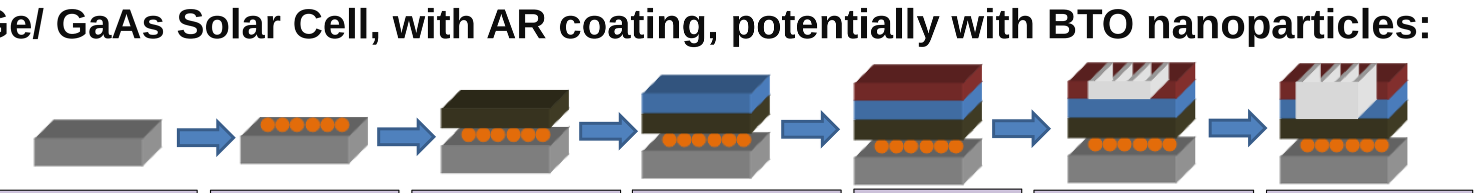
Sonicate MgO substrate in acetone.	Deposit 100 nm Ti via sputtering.	Deposit 250 nm Ge via e-beam.	Deposit 20 nm Au via e-beam.	Deposit 150 nm Al via sputtering.	Attach Cu wire via Ag paste.

Ge/ GaAs Solar Cell:

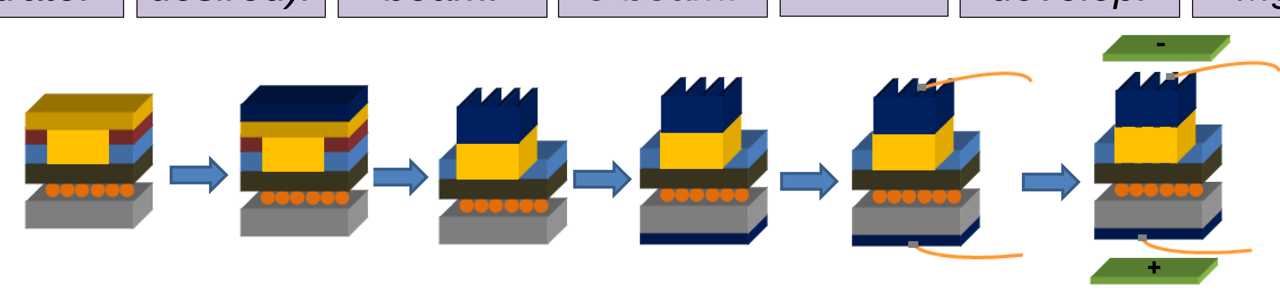


Sonicate & etch GaAs substrate.[5]	Deposit 500 nm Ge via sputtering.	Deposit 10 nm Au via e-beam.	Deposit 200 nm Al via sputtering.	Attach Cu wire via Ag paste.

Ge/ GaAs Solar Cell, with AR coating, potentially with BTO nanoparticles:



Sonicate & etch GaAs substrate.[5]	Spin-coat on BTO (if desired).	Deposit 250 nm Ge via e-beam.	Deposit 80 nm MgO via e-beam.	Spin-coat on + PR	Use mask, expose to UV light, develop.	Etch the exposed MgO.[6]



Deposit 20 nm Au via e-beam.	Deposit 150 nm Al via sputtering.	Wash away PR with remover.	Deposit 200 nm Al via sputtering.	Attach Cu wire via Ag paste.	Pole BTO at 20 kV/ cm at 120 °C.

Film Characterization

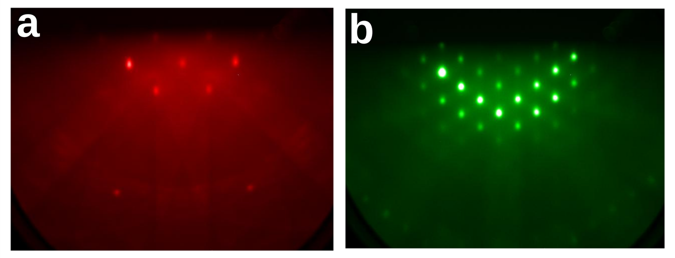


Figure 3. *Example RHEED Images of GaAs (2a) and Ge (2b). Both are epitaxial.*

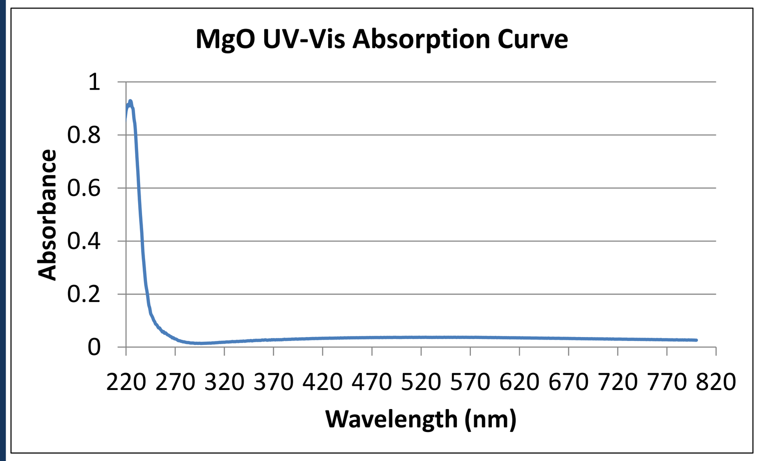


Figure 4. *Based on the UV-Vis curve, it is clear that MgO is transparent to visible light as desired.*

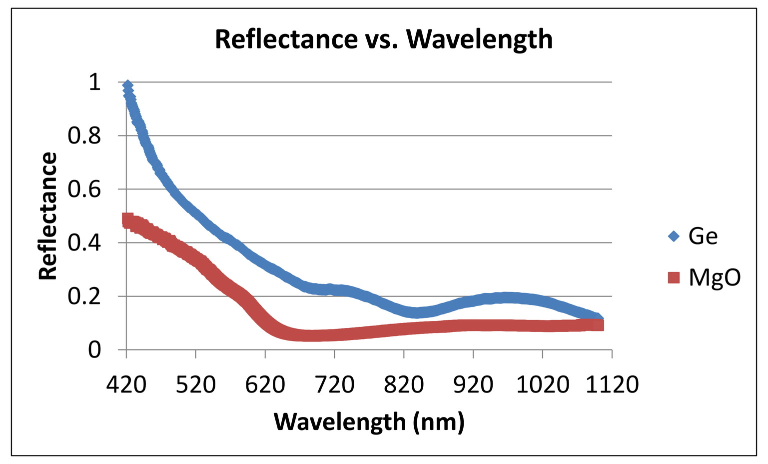


Figure 5. *MgO serves as a great AR coating-especially at lower wavelengths.*

I-V Curves

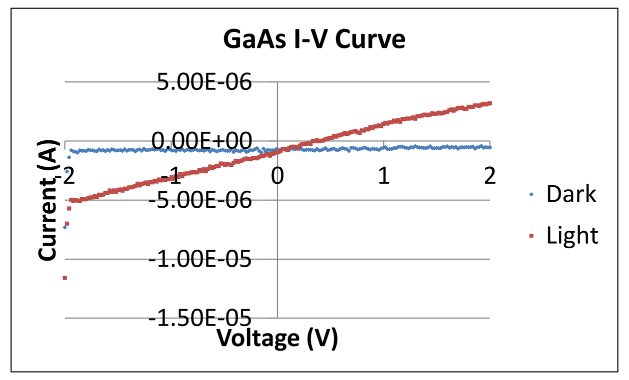


Figure 6. *GaAs I-V curve. A solar effect is clearly seen upon comparison between light and dark curves. However, the light curve is quite linear. No rectifying effect is observed.*

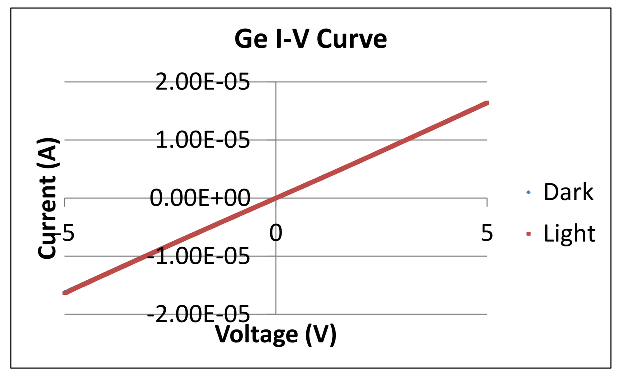


Figure 7. *Ge I-V curve. No solar effect is observed. The light and dark curves are the same in this case.*

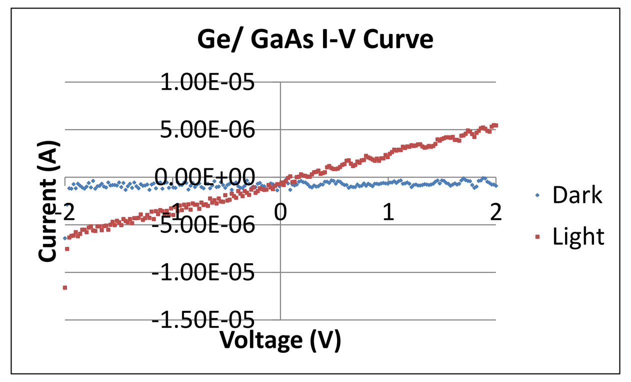


Figure 8. *Ge/ GaAs I-V curve. A solar effect is clearly seen upon comparison between light and dark curves. Again, the curve is quite linear.*

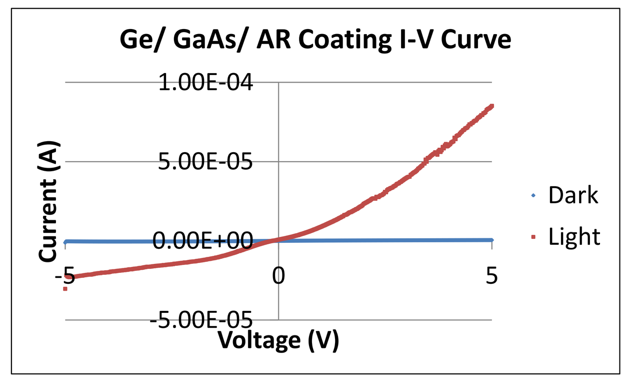


Figure 9. *Ge/ GaAs with AR coating I-V curve. A clear improvement is seen from the AR coating. There is a non-linearity as desired. A rectifying effect is observed.*

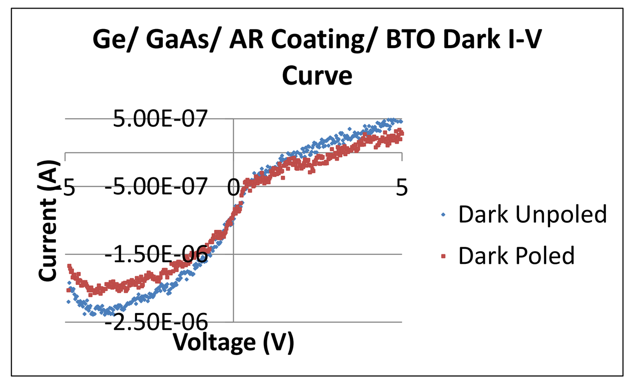


Figure 10. *With BTO dark I-V curve. The poled BTO reduced the dark current as desired.*

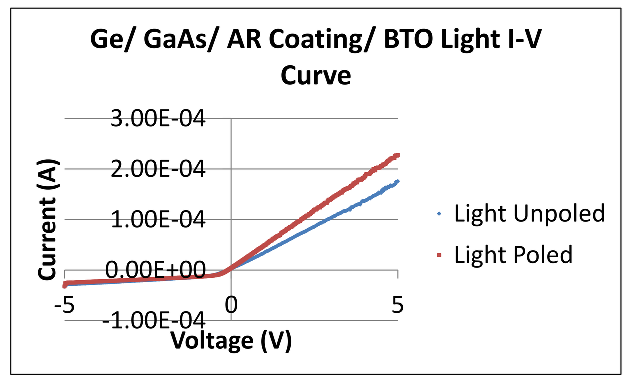


Figure 11. *With BTO light I-V curve. The poled BTO increased the light current and non-linearity as desired.*

Conclusions

- •Optimum epitaxial growth conditions of Ge on GaAs were found. The conditions were using e-beam deposition at a temperature of 500 °C, with a rate of 0.2Å/ sec, and a film thickness of 250 nm.
- •MgO was optically transparent and reduced sample reflectance from 44% to 27% at a wavelength of 550 nm. MgO also generated a rectifying effect in the I-V curve.
- •Poled BTO nanoparticles reduced the dark current and increased the light current. The nanoparticles also enhanced the rectifying effect in the I-V curve.
- •Ge did not show any photovoltaic response.

References

1. Circuits Today, Understanding *the PN Junction*, WWW Document, (http://www.circuitstoday.com/understanding-the-pn-junction).
2. C. Kittel, *Introduction to Solid State Physics,* 8th Ed. (John Wiley & Sons Inc, Hoboken, NJ, 2005), p. 190.
3. M.A. Green et al, *Progress in Photovoltaics*, WWW Document, (http://onlinelibrary.wiley.com/doi/10.1002/pip.2573/full)
4. Logitech Materials Technologies & Engineers, *Gallium Arsenide,* WWW Document, (http://www.logitech.uk.com/applications/gallium-arsenide.aspx)
5. J.S. Song et al, *Journal of Crystal Growth* **264** , pp. 98-103 (2004).
6. J. Karthik, Anoop R. Damodaran, & Lane W. Martin, *Journal of Advanced Materials* **24**, pp. 1610-1615 (2012).

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