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Performance Comparison of Top and Bottom Contact Gallium Arsenide (GaAs) Solar Cell

by Naresh C Das

ARL-TR-7054 September 2014

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Naresh C Das
Sensors and Electron Devices Directorate, ARL

REPORT DOCUMENTATION PAGE						*Form Approved OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)* September 2014	**2. REPORT TYPE** Final	**3. DATES COVERED (From - To)** 01/02/2014–07/15/2014
4. TITLE AND SUBTITLE Performance Comparison of Top and Bottom Contact Gallium Arsenide (GaAs) Solar Cell		**5a. CONTRACT NUMBER** **5b. GRANT NUMBER** **5c. PROGRAM ELEMENT NUMBER**
6. AUTHOR(S) Naresh C Das		**5d. PROJECT NUMBER** **5e. TASK NUMBER** **5f. WORK UNIT NUMBER**
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory ATTN: RDRL-SEE-M 2800 Powder Mill Road Adelphi, MD 20783-1138		**8. PERFORMING ORGANIZATION REPORT NUMBER** ARL-TR-7054
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		**10. SPONSOR/MONITOR'S ACRONYM(S)** **11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

We fabricated single-junction solar cell on epitaxially grown n-type gallium arsenide (GaAs) substrate. We used a germanium (Ge)/gold (Au)/nickel (Ni)/Au metal contact from the top side on a highly doped n-type epitaxial layer as well as the bottom side on a n-type GaAs substrate. We observed 10–15% increase in solar cell power when the top contact is used for the n-type GaAs epi layer compared to the bottom side n- type GaAs substrate. Solar cell fill factor, sheet, and shunt resistances are same for both the top and bottom contact type devices. We conclude that to achieve higher power, it is advantageous to use an n-type contact from a highly doped top *n* epitaxial layer rather than a bottom n-type GaAs substrate.

15. SUBJECT TERMS

Gallium arsenide, GaAs solar cell, efficiency, top contact, anti reflection coating

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Naresh C Das
A. Report Unclassified	**b. ABSTRACT** Unclassified	**c. THIS PAGE** Unclassified	UU	14	**19b. TELEPHONE NUMBER** (*Include area code*) (301) 394-5500

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

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1. Introduction

The performance of state-of-the-art III-V gallium arsenide (GaAs) solar cells is excellent. Due to their direct bandgap electronic structure, they are able to absorb 97% of the AM1 radiation in a thickness of 2 µm. Another important application of GaAs solar cells is in the concentrated solar power area with an irradiation intensity of more than 1000 suns. The Spire GaAs solar cell with 27.6% at 255 suns has the highest efficiency reported for a single-junction solar cell operating under concentrated light.[1] Many attempts have been made to improve the GaAs solar cell performance by using a single double-layer anti-reflection coating (ARC) as well as surface engineering including nanostructure formation.[2] Yu et al. achieved a 28% enhancement in solar cell power by using indium tin oxide nano columns on GaAs solar cells by oblique-angle deposition.[3] Most of the reported results use GaAs cells with bottom contact metal deposited by blanket deposition on the bottom surface of the GaAs substrate. This method is easy and the most cost-effective way of solar cell fabrication. Though very few papers reported GaAs solar cell with a top n-type contact,[4] to the best of our knowledge, no one has made a comparative study of solar cell performance with a bottom n-type contact and a top n-type contact on highly doped epitaxial layer structures.

Here we compare solar cell performance with either a top or bottom n-type contact. We found that there is about 10–15% increase in solar energy harvesting power when a top n-type contact is used compared to a bottom n-type contact device.

2. Experimental

The single-junction GaAs solar cell p- on n-type structure is fabricated using the molecular beam epitaxy (MBE) technique. Table 1 shows the details of the epitaxial structure used to fabricate the solar cell. After initial cleaning, a lightly doped 200-Å n-type GaAs layer is deposited at 590 °C. Following the first deposition, the temperature is lowered to 580 °C and the rest of the layers are deposited as shown in Table 1. Solar cell device fabrication starts with etching of the mesa region using inductively coupled plasma (ICP) etching with boron trichloride (BCl_3) gas until the bottom n-type GaAs layer is reached. We use RF1 and RF2 powers of 150 and 500 W, respectively. A 30-s chemical etch (hydrochloric acid [HCl]: water [H_2O]-1:1) is used to remove any oxide prior to the ICP etch. We carefully performed the etching experiment, so that we would not over etch and go beyond the n+ bottom layer. For the p-type contact metal, we created a titanium (Ti)/platinum (Pt)/gold (Au) (300/500/2500 Å) three-layer deposition process using an electron beam evaporation tool. Following the creation of the double-layer ARC with silicon dioxide (SiO_2)/silicon nitride (Si_3N_4) and a window opening, we used a germanium (Ge)/Au/

nickel (Ni)/Au (300/500/200/2500 Å) four-layer metal film for the n-contact on both the top and bottom layers. We used a 60-s rapid thermal anneal (RTA) process at 380 °C to anneal the contacts.

Table 1 GaAs single-junction solar cell structure

Material Composition	**Doping level (cm^{-3})**	**Thickness (Å)**	**Comment; Function; Repeats**
GaAs	P = 2E19	200	T_{sub} = 580 °C
$Al_{0.8}Ga_{0.2}As$	P = 5E18	300	T_{sub} = 580 °C
GaAs Emitter	P = 5E18	4,000	T_{sub} = 580 °C
GaAs	Undoped	10,000	T_{sub} = 580 °C
GaAs Base	N = 2E17	20,000	T_{sub} = 580 °C
$Al_{0.2}Ga_{0.8}As$	N = 5E18	300	T_{sub} = 580 °C
GaAs	N = 5E18	2,000	T_{sub} = 595 °C
GaAs substrate	N +		

Figure 1 shows the cross-sectional view of the solar cell. As seen in the figure, we can have access to apply bias to the n-type contact either through the top epitaxial layer or the bottom n-type substrate. The top n-type contact connects to the heavily doped n-layer, whereas the bottom contact connects to the lightly doped GaAs substrate material. The top n-type contact has a ring structure all around the p-type mesa region. As also seen in Fig. 1, the p-type metal has a grid pattern so that the photo-generated carriers can be collected with minimum drift from the origin of their creation.

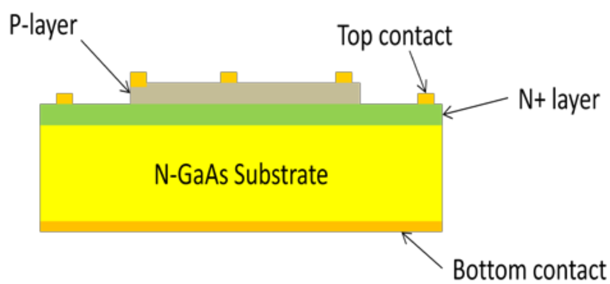

Fig. 1 Cross-sectional view of GaAs solar cell

A photograph of part of the processed chip is shown in Fig. 2. Here we show the top and bottom contact pads that we use on the probe station to test the solar cell's performance. Since the device has ARC, the top mesa surface exhibits a black color. The gap between the edge of the mesa region and the n-type metal pad is 20 µm. Similarly, the gap between the p-type metal and the edge of the mesa region is 10 µm.

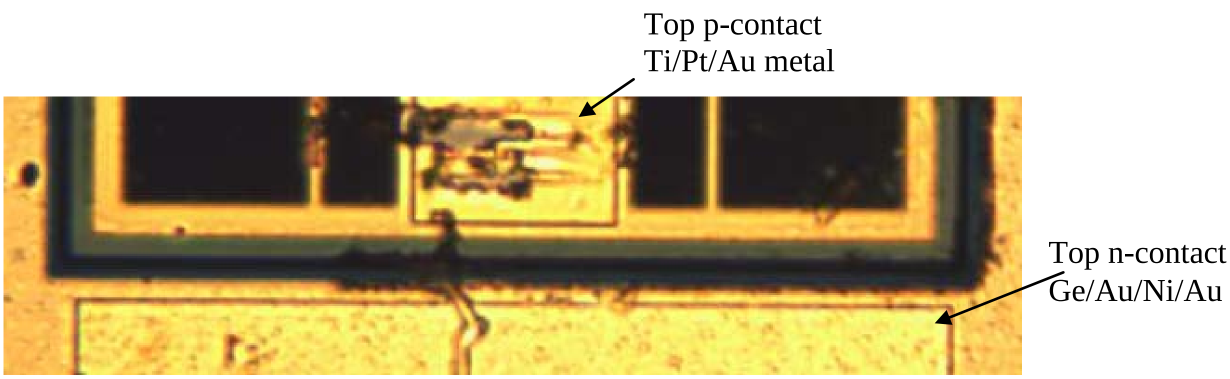

Fig. 2 Photograph of the processed solar cell

3. Results and Discussion

In Fig. 3, we show the dark current versus voltage of the top and bottom contact devices. The dark and illuminated current versus voltage (*I-V*) measurements were taken using an Agilent HP 4156 C parametric analyzer. The dark current is plotted in the logarithmic scale. We didn't see any appreciable difference for dark currents between the two types of devices. Hence, the number of defects responsible for dark current for both types of configurations is the same. Also in the subthreshold region of the device's operation (0.5 to 1.0 V), the slope of the current for both devices is the same. Hence, the sheet and shunt resistances of the devices are the same.

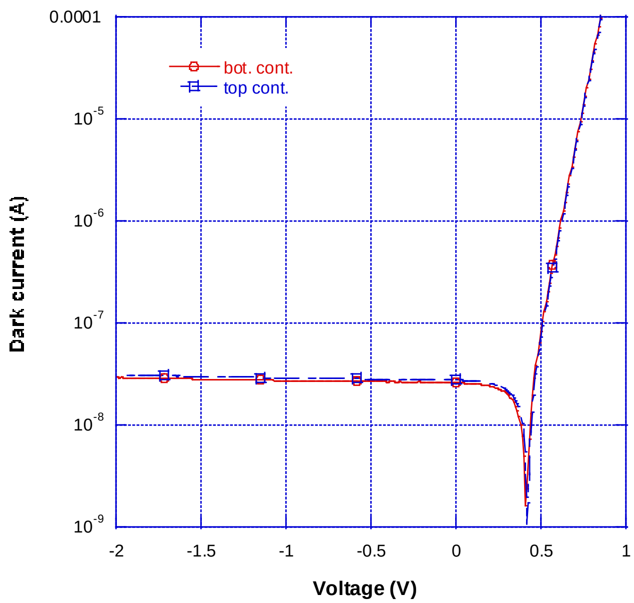

Fig. 3 Dark current of both the top and bottom n-type contact solar cells

The current versus voltage for both the top and bottom contact devices at AM1.5G is shown in Fig. 4. An unfiltered Newport solar simulator provided broadband illumination with an equivalent AM1.5G illumination intensity of approximately 1.0 sun (100 mW/cm^2). We tested these devices using a probe station. The short circuit current (I_{sc}) for the top contact device is 26.5 mA/cm^2, which is very close to the world record I_{sc} number for a GaAs single-junction device. We observed about a 13% increase in the short circuit current for the top contact device compared to the bottom contact device. The open circuit voltages (V_{oc}) for both the configurations have same value of 0.82 V. As also seen in Fig. 4, the subthreshold slope of the *I-V* curves is the same for both devices, showing that the sheet resistances of these devices are the same.

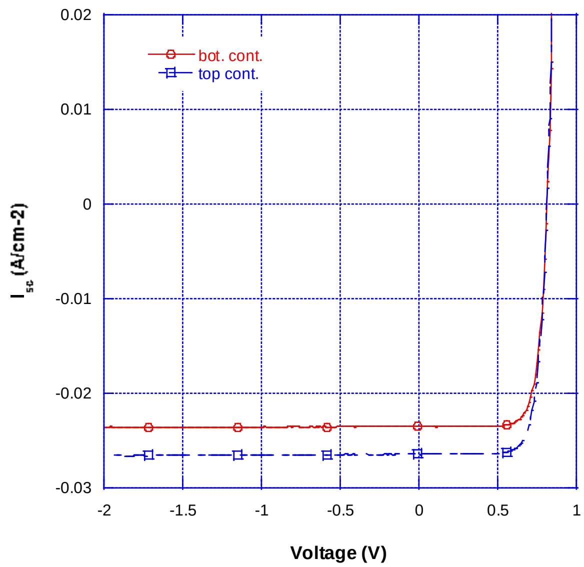

Fig. 4 Current vs. voltage of solar cells with AM1.0 solar cell irradiation

The solar cell power versus voltage is shown in Fig. 5. The data in Fig. 4, in the voltage range of 0 to V_{oc}, are used to plot the power versus voltage curves in Fig. 5. We observed about an 11% increase in peak power for the top contact devices compared to the bottom contact devices. This is a significant improvement in solar power harvesting capability with a minimal process change. The solar cell external power conversion efficiencies of the bottom and top contact devices are 14.8% and 16.5%, respectively. However, these numbers are well below state-of-the-art GaAs solar cell efficiency values, so we have more room for improvement in the fabrication process and material growth of our devices. The result is nonetheless very encouraging, as we received these significant device performances in our first attempt. The design of the epitaxial layer thickness, doping, and the p-contact layer grid patterns are a few parameters that we will try to optimize to improve the overall solar cell efficiency.

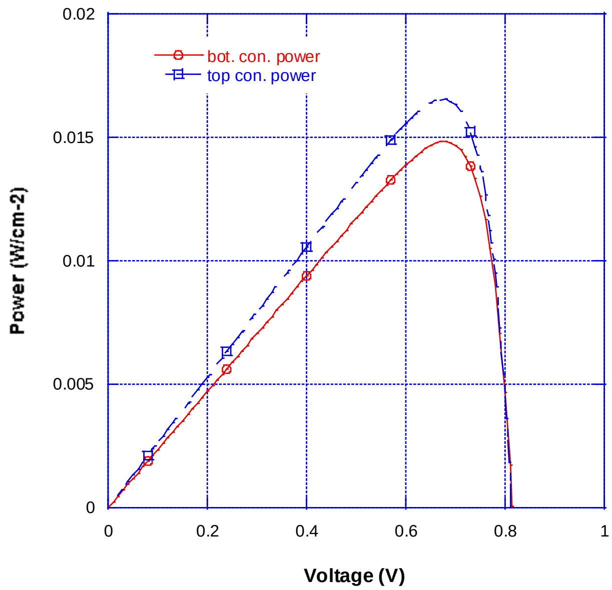

Fig. 5   Power versus voltage for top and bottom contact solar cells

We presented here our findings on solar cell performance with top and bottom contact configurations for an n-type contact in a solar cell device. From Figs. 4 and 5, we found out that the slopes of the *I-V* curves were the same for both types of device. Hence, we conclude that the series resistances of the solar cells for both configurations are the same. We believe the difference in the short circuit currents, as seen in Fig. 4, may be due to the higher number of carriers available for the top contact devices as compared to the bottom contact devices due to the high n-type doping in the epitaxial layer as compared to the doping of an n-type GaAs substrate. We believe the measurements of carrier lifetime and density in the epitaxial layer will be more rewarding.

4. Conclusions

We reported a 10–15% increase in GaAs solar cell harvesting power when the device used a top n-type contact configuration rather than a bottom n-type contact configuration. Our observed short circuit current of 26.5 mA/cm^2 is very close to the state-of-the-art I_{sc} value for GaAs single-junction solar cell devices. Since most of the solar cell production runs use a bottom n-type contact configuration, our results will be useful in redesigning the solar cell structure to produce devices featuring a top contact configuration to harvest additional power.

5. References

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List of Symbols, Abbreviations, and Acronyms

ARC	anti-reflection coating
Au	gold
BCl_3	boron trichloride
GaAs	gallium arsenide
Ge	germanium
H_2O	water
HCl	hydrochloric acid
ICP	inductively coupled plasma
I-V	current versus voltage
MBE	molecular beam epitaxy
Ni	nickel
Pt	platinum
RTA	rapid thermal anneal
Si_3N_4	silicon nitride
SiO_2	silicon dioxide
Ti	titanium

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