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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
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Development of 1.25 eV InGaAsN for Triple Junction Solar Cells

N. Y. Li, P. R. Sharps, 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

Development of next generation high efficiency space monolithic multijunction solar cells will involve the development of new materials lattice matched to GaAs. One promising material is 1.05 eV InGaAsN, to be used in a four junction $GaInP_2$/GaAs/InGaAsN/Ge device. The AM0 theoretical efficiency of such a device is 38-42%. Development of the 1.05 eV InGaAsN material for photovoltaic applications, however, has been difficult. Low electron mobilities and short minority carrier lifetimes have resulted in short minority carrier diffusion lengths. Increasing the nitrogen incorporation decreases the minority carrier lifetime.

We are looking at a more modest proposal, developing 1.25 eV InGaAsN for a triple junction $GaInP_2$/InGaAsN/Ge device. The AM0 theoretical efficiency of this device is 30-34%. Less nitrogen and indium are required to lower the bandgap to 1.25 eV and maintain the lattice matching to GaAs. Hence, development and optimization of the 1.25 eV material for photovoltaic devices should be easier than that for the 1.05 eV material.

Figure 1 is a schematic of the test structures that we are growing to evaluate the 1.25 eV InGaAsN material. We have found that the best way to evaluate the InGaAsN material is to grow, process, and test actual photovoltaic devices. Because EMCORE's current $GaInP_2$/GaAs dual and $GaInP_2$/GaAs/Ge triple junction cells have the n-on-p configuration, we are looking at n-on-p InGaAsN junctions. The thicker $GaInP_2$ window is chosen to give an indication of how the InGaAsN would actually perform in a triple junction device. We have looked at 3 μm and thinner InGaAsN base thicknesses. The

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thinner InGaAsN bases are used because growth of InGaAsN requires a large amount of dimethylhydrazine, and hence growth of thick layers is expensive. Trimethylgallium, triethylgallium, solution trimethylindium, diethylzinc, disilane, arsine, and phosphine are the other precursors used in the growth of the devices. Cells 1 cm^2 in area are processed using standard III-V device processing techniques.

		Metal
		n^+-GaAs 0.5 µm 7×10^{18} cm^{-3}
n^+-InGaP$_2$	0.7 µm	2×10^{18} cm^{-3}
n^+-InGaAsN	0.2 µm	2×10^{18} cm^{-3}
p-InGaAsN	1.5 µm	2×10^{17} cm^{-3}
p-GaAs	1 µm	5×10^{17} cm^{-3}
p-GaAs Substrate		
Metal		

Figure 1. Schematic of the basic InGaAsN cell structure.

Table 1 contains a summary of different InGaAsN growth conditions that we have examined. We have primarily looked at growth rate and post-growth annealing temperature. We have also used several different dimethylhydrazine sources from different vendors, but have seen little effect on device results.

Run#	Window Mat'l	W(Å)	BSF Mat'l	BSF(Å)	Base(µm)	Emitter(µm)	Rg (A/s)	650°C, N_2
9ky034-02	InGaP	6700	GaAs	500	3	0.2	~20	4 mins
9ly01A-06	InGaP	5450	GaAs	500	3	0.1	~20	4 mins
9ly01B-03	InGaP	5450	GaAs	500	3	0.1	~20	30 mins
9ly06A-06	InGaP	6700	(Al)GaAs	250	1.2	0.2	~12	30 mins
9ly06B-06	InGaP	6700	(Al)GaAs	250	1.2	0.2	~12	45 mins
9ly019-06	InGaP	6700	(Al)GaAs	250	1.2	0.2	~7.2	30 mins
0ay18A-06	InGaP	6700	(Al)GaAs	250	1.8	0.2	~7.2	45 mins
0ay18B-05	InGaP	6700	(Al)GaAs	250	1.8	0.2	~7.2	60 mins

Table 1. Summary of growth conditions and structure for InGaAsN solar cells. W(Å) refers to the window thickness in angstroms, Rg (Å/s) refers to the growth rate in angstroms/sec, and 650°C, N_2 refers to the post growth annealing time and temperature.

Table 2 has the device results for the growth conditions described in Table 1. The currents, voltages, and fill factors all lower than expected for a material with bandgap of 1.25 eV. To be current matched with a GaInP$_2$ upper cell in a triple junction device, the InGaAsN would need to generate about 20 mA/cm^2. The devices do not have an anti-reflection coating (ARC). Reflection off of the front surface is about 30%, so addition of the ARC would add about 3-4 mA/cm2 to the currents shown in Table 2. Increasing the base thickness does not add significantly to the current. Figure 2 has the IQE curves for several of the devices in Tables 1 and 2. While being able to achieve a peak IQE close to the band edge, there is significant roll off at longer wavelengths. An increased base thickness (9ly0001B-03) did not increase the IQE at longer wavelengths, compared to a thinner base thickness ((0ay0018C-03). This is consistent with a short minority carrier diffusion length in the p-type base, rather than due to insufficient absorption in the base.

Run#	PIQE	Voc, mV	Jsc, mA/cm2	FF	Eff, %
9ky034-02	0.57	680.4	8	61.2	2.4
9ly01A-06	0.72	741.2	10.25	73	4.1
9ly01B-03	0.77	756.6	11.6	72.9	4.6
9ly06A-06	0.61	640.6	9.5	71.2	3.2
9ly06B-06	0.64	647.2	10.1	69.6	3.3
9ly019-06	0.76	711.7	9.9		
0ay18A-06	0.82	714.58	9.84	61.7	3.2
0ay18B-05	0.83	733.4	10.56	62.7	3.6
0ay18C-03	0.74	747.65	10.74	65	3.8

Table 2. Summary of results for InGaAsN devices. PIQE refers to the peak internal quantum efficiency. All devices are 1 cm^2 in area, were measured under simulated AM0 illumination, and do not have anti-reflection coatings.

The lower than expected voltages in Table 2, for a material of 1.25 eV bandgap, are consistent with the lower currents and short minority carrier diffusion lengths. A short minority carrier lifetime and high bulk recombination are the most likely explanation for the low currents and voltages.

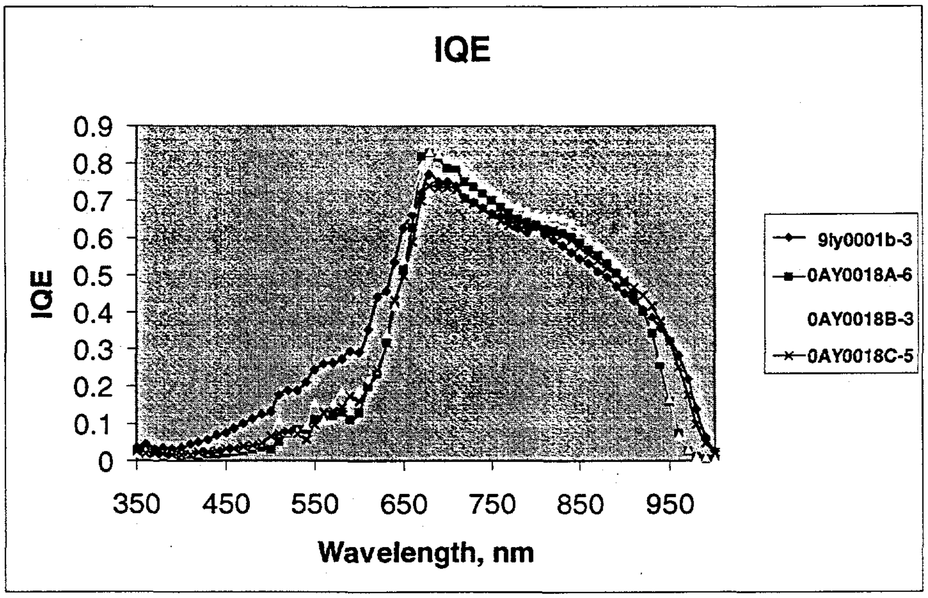

Figure 2. IQE curves for several samples. See text for discussion.

The longer post-growth annealing time also improves device performance. We are not certain as to the exact mechanism causing this. Work is ongoing to further improve the InGaAsN material quality. Different precursors, different growth conditions, and different post-growth treatments are all being examined, with the results to be presented at the conference.