NON-DESTRUCTIVE TESTING BY ABSOLUTE ROOM TEMPERATURE PHOTOLUMINESCENCE QUANTUM EFFICIENCY OF GaAs SOLAR CELLS

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INTRODUCTION

Nondestructive room temperature photoluminescence (PL) measurements on semiconductors are an important characterization tool to evaluate material quality and study the opto-electronic conversion mechanism involved in devices such as light-emitting diodes, solar cells, etc. [1, 2]. In this paper, we will describe non-destructive PL characterization studies of partially processed GaAs solar cells. Such a tool is valuable in process development of high performance solar cells.

EXPERIMENTAL SETUP

The experimental procedure employed for absolute calibration is similar to that in Reference 1, with the PL from the active layer being referenced against the scattered light from a reflective Lambertian white surface placed in the identical optical set up, as shown in Figure 1.

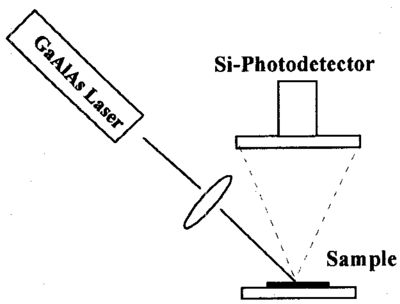

Fig 1. Experimental PL set-up.

An AlGaAs laser (780nm) was used as a pump source, and photoluminescence at 880nm was collected by a Si-photodetector through a 830nm long pass color filter. A conventional p-AlGaAs/n-GaAs/AlGaAs double heterostructure was grown over a 500-Å-thick AlAs release layer by organometallic chemical vapor deposition, as shown in Figure 2 [3].

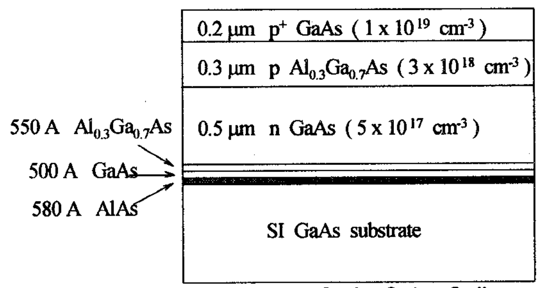

Fig. 2 Heterostructure for the GaAs Solar Cells.

CALIBRATION

For efficiency calibration purposes, we used a simple optical model for the known absorption and reflection from a GaAs substrate. Internal quantum efficiency η_{int} was evaluated from the measured value for the external efficiency η_{ext}, which is given by the relationship:

$$\eta_{ext} = V_{PL} / (T_1 \; T_2 \; T_F \; A_p \; C \; V_{White})$$

$$\eta_{int} = 4n^2 x \eta_{ext} \quad \text{(if the escape angle is small enough)}$$

where the measured PL output signal V_{PL} is referenced to the fraction of the input absorbed by the active layer. T_1 and T_2 are the Fresnel transmission coefficients of pump light going in and PL coming out of the medium. T_F is the photoluminescence transmission of the pump blocking filter. A_p is the absorption term which is equal to 1-exp(-aL), where a is the absorption coefficient and L is the thickness of the active n-GaAs layer. C is the correction factor ≈ 1, for the difference of responsivity of the photodetector at the luminescence wavelength 880nm and the pump wavelength 780nm. V_{White} is the scattered signal of the reference white surface whose reflectivity is unity. For a plane surface, the escape cone of only 16°, imposed by Snell's law, covers a solid angle of only ≈ $(1/4n^2)\times4\pi$ steradians. Because the refractive index at 880nm is about 3.5 for GaAs, the external efficiency would be ≈ 2.0% for internal efficiency of 100%. From the measurements, the internal

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efficiency was found to be ≥ 90% which indicates the good quality of the sample.

PREDICTING J_c

From the luminescence efficiency versus pump intensity we can determine the I-V curve. As shown in Figure 3,

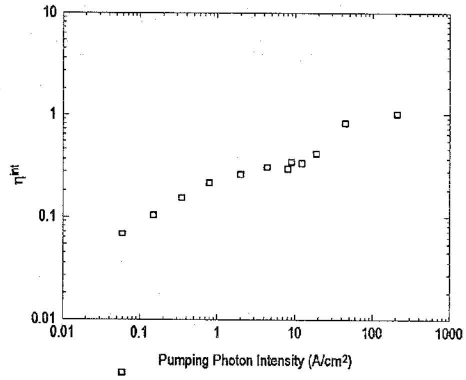

Fig 3. Internal quantum efficiency h_{int} from PL measurements of the GaAs heterostructure with different pumping photon-intensity.

the PL signal decreases below 50% when the excitation photo-current density is $J_c \approx$ 5-50 A/cm^2. J_c represents the cross-over transition from radiative recombination to non-radiative recombination. Electrically, the transition point from the electrical diffusion regime (low-injection) to the recombination regime is $J_c = (J_{02})^2 / J_{01}$, where J_{01} is the pre-factor of the n = 1 radiative current and J_{02} is the pre-factor of the n = 2 non-radiative current. The narrow-base diffusion model gives us a saturation current of diffusion $J_{01} \approx 1.3\times10^{-20}$ A/cm^2. Therefore, plugging J_{01} and J_c into the above equation, we obtain optical $J_{02} \approx 2.5\times10^{-10} - 8.0\times10^{-10}$A/cm^2. From the I-V curve of the fully processed solar cell diode, electrical J_{02} is observed to be $\approx 4.3\times10^{-10}$A/cm^2. This value lies within the range predicted from the PL data, indicating good qualitative agreement between the optical and electrical measurement techniques.

ETCHING RATE CALIBRATION

A simple application of our approach is to calibrate etch rates and epi-layer thickness. We rely upon the efficiency drop when the wide bandgap hetero-layers are removed by etching. To characterize the sample, we used H_2SO_4:H_2O_2:H_2O (1:8:500) to non-selectively etch a small piece cut from the wafer. The PL intensity was measured after every 30 seconds of etching, as shown in Figure 4.

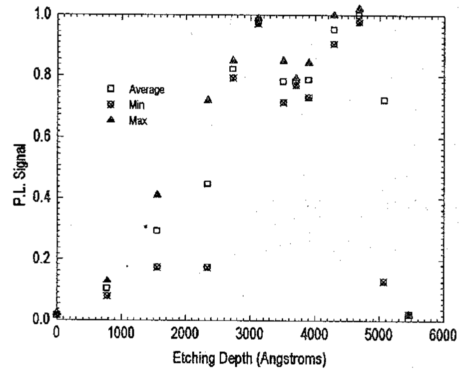

Fig 4. PL measurements of the GaAs heterostructure during the etching.

The final drop in this plot is due to the loss of carrier confinement when the cladding layer (p-AlGaAs) is etched and removed.

SUMMARY

In summary, we have performed contactless photoluminescence characterization of GaAs solar cells. Besides the calibration of absolute internal quantum efficiency, J_{02} from PL characterization is 2.5×10^{-10} - 8.0×10^{-10}A/cm^2 compared with 4.3×10^{-10}A/cm^2 from the electrical I-V curve. These preliminary results show that contactless absolute PL characterization is a useful tool for process development of solar cells.

References:

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[3]. X. Y. Lee, Ashish K. Verma, Charles Q. Wu, Mark Goertemiller, Jack Eldridge, David Lillington and Eli Yablonovitch, "Thin Film GaAs Solar Cells on Glass Substrate by Epitaxial Liftoff", to be submitted to the *Conf. Rec., 25th IEEE Photovoltaic Specialists Conf.*, Washington, DC, May 1996.

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