CAPACITANCE TRANSIENTS IN p-TYPE GaAs MOS STRUCTURES AND APPLICATION TO LIFETIME MAPPING DURING SOLAR CELL FABRICATION*

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ABSTRACT

In recent years, analysis of capacitance transients in small-area MOS capacitors has made it possible to obtain extremely localized values of the minority carrier generation lifetime in silicon single-crystal wafers and in devices made from this semiconductor. For example, Schwuttke, et al. (ref. 1) have used this technique to produce generation lifetime maps on silicon wafers. They have shown that the values of generation lifetime can vary widely from point to point and that the values are extremely sensitive to crystal growth and wafer-handling procedures. They have shown that there is a correlation between the performance of recombination lifetime dependent parameters of semiconductor devices made at various locations on a silicon wafer and the generation lifetime at those locations. More recently, Baliga and Adler (ref. 2) obtained lifetime versus depth profiles in diffuse layers of Si. The development of low-temperature oxide preparation techniques has led to the application of this method for monitoring the lifetime at many stages in the fabrication of Si power devices (ref. 3). It could, therefore, be used to monitor τ at the various stages in the manufacture of solar cells.

It is a feature of this lifetime measurement method that the time constant of the capacitance transient is related to the generation lifetime through the ratio of doping concentration N to the intrinsic carrier concentration n_i in the semiconductor. Thus in the case of Si having N_O of $10^{16}/cm^3$, the capacitance decay constant τ_c is 10^6 times the generation lifetime τ_g so that, if $\tau_g = 1$ μsec, $\tau_c = 1$ sec. This shift of time scales is particularly advantageous when applied to measuring, mapping, and profiling minority carrier lifetimes in direct gap semiconductors with bandgaps larger than Si and therefore n_i values substantially lower than in Si. For example, a nanosecond lifetime in p-type GaAs having acceptor concentrations N_A of $10^{16}/cm^3$ would give rise to a capacitance decay constant of several seconds. Until now, however, this technique for measuring τ_g has been limited to silicon because that is the only semiconductor on whose surface it has been possible to produce the high-quality native oxide required in

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MOS capacitors intended for such studies. The oxide must allow the surface to be driven into deep inversion by a voltage pulse; the transient occurs as carriers generated in the space charge region of the semiconductor accumulate at the surface.

In this paper we report on fabrication on p-type GaAs of MOS structures in which the quality of the oxide is such that the surface can be driven into deep inversion by a voltage pulse. We have measured the capacitance transients in such MOS capacitors as a function of step amplitude and temperature and have analyzed the transients by an extension of the method developed by Zerbst (ref. 4) for silicon. The oxides were produced by plasma oxidation on an LPE-grown p-type GaAs specimen with N_A of $3x10^{17}/cm^3$. The capacitors were produced by depositing 50-μm-diameter gold dots over the native oxide and, therefore, the lifetime is localized to the area under the dot. The method permits extraction of both the bulk lifetime and the interface recombination velocity. We have measured these parameters on samples with different N_A and have found a correlation between τ_g and N_A. Lifetime values in the range of several tenths of a nanosecond to about 1 nanosecond have been observed on our particular wafers; interface recombination velocities in the range of 10^5 cm/sec were observed. However, our GaAs was from a single source and was a small sampling of the variety possible in GaAs; therefore, we do not mean to attach much significance to the "uniformity" of τ_g in our specimens. The important part of our message is that it is possible to produce high-quality native oxides on GaAs and that this important technological advance makes possible lifetime measurement, mapping, and profiling in this material. Further development of this technique should allow monitoring of the effects of various processing steps on the lifetime of GaAs and, therefore, ultimately on the performance of GaAs solar cells.

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ANNEALING IN ELECTRON IRRADIATED AlGaAs SOLAR CELLS*

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SUMMARY

Preliminary data is presented on the annealing characteristics of AlGaAs solar cells. Devices with varying AlAs "window" thickness and junction depth were irradiated with 1 MeV electrons, at two different temperatures, to 1×10^{15} e/cm^2. Additional annealing data on AlGaAs cells exposed to 1×10^{16} e/cm^2 is also described.

INTRODUCTION

It has been shown that properly fabricated AlGaAs solar cells display initial power output and performance under electron irradiation that is superior to even advanced laboratory silicon solar cells (ref. 1 and 2). This work was done as part of the JPL program to investigate the potential of thermal annealing as a means of extending the operating lifetime of solar cell arrays. The data reported from the NTS-2 flight experiment (ref. 3 and 4) also acted as an incentive to examine the effect of irradiating AlGaAs solar cells at elevated temperature.

EXPERIMENTAL METHOD

All the irradiations were performed with the JPL Dynamitron using 1 MeV electrons. A complete description of this facility may be found in reference 5. The initial experiment was devised to examine the effect of cell temperature during irradiation on electrical performance. All cells used in this test were obtained from Hughes Research Labs (HRL). The AlAs window layer was less than 0.5 m and the junction depth was between 0.4 and 0.5 μm.

Five cells were mounted to a temperature controlled copper block and held at 125°C under vacuum during the irradiation. In order to give the samples an opportunity to anneal during this test, the flux was reduced to 2×10^{10} e/cm^2-sec. The cells received a total fluence of 1×10^{15} e/cm^2. I-V measurements at 28°C AMO intensity were made before and after the test while the cells were in the target chamber. A second group of five cells were than irradiated at

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28°C using the same flux and fluence as the previous test, and pre and post-irradiation I-V data was obtained.

Once this test was concluded, two cells from each test group were placed on a quartz boat and held within the constant temperature zone of a diffusion furnace under flowing nitrogen. I-V data at 28°C under AMO conditions was recorded after each heat treatment. The tests began at 200°C, and were continued, in 50°C increments, to a final temperature of 400°C. Time at any temperature ranged from 15 to 110 minutes.

In another test a group of four AlGaAs cells supplied by HRL were irradiated to fluence levels of $1x10^{15}$ and then $1x10^{16}$ e/cm^2 under vacuum, employing normal fluence ($1x10^{12}$ e/cm^2-sec). The window layer thickness of these devices was 1.1 μm and the junction depth 0.3 μm. I-V data was obtained after each fluence level. One cell of each type was then given post irradiation heat treatments at 200°C in order to investigate annealing behavior as a function of time at temperature.

RESULTS AND DISCUSSION

There was no difference in electrical degradation between the cell groups irradiated at different temperatures. A summary of the pre and post testing electrical data, as well as the results of an additional 125°C heat treatment of those cells irradiated 28°C is given in Table 1. This is unexpected in view of the flight experiment information of references 3 and 4. It is possible that the higher fluence used in this experiment may have masked voltage and fill factor annealing or that this annealing phenomenon occurs only when the cells are exposed to the proton spectrum of space.

The recovery of output power as a function of annealing temperature is plotted in figure 1. After 15 min. at 200°C, the samples had regained nearly 10 percent of the power lost during the irradiation. The percentage of recovery reached over 70 percent after 110 min. at 250°C. However, higher annealing temperatures did not seem to have a significant influence on maximum power recovery, in fact there was some degradation in output at temperatures of 350 to 400°C. It was also noticed that the antireflection coatings were becoming paler in color at ∿400°C. After a 30 min. anneal at 400°C the samples began to display evidence of contact shunting. The shunting became extreme after an hour at this temperature and the experiment was discontinued.

Figure 2 shows the effect of annealing time at 200°C on the recovery of two AlGaAs cells which had been irradiated to $1x10^{16}$ e/cm^2. Table 2 contains the pertinent electrical data for the samples after $1x10^{15}$ and $1x10^{16}$ e/cm^2. There is a great deal of recovery in output power exhibited at 200°C, and it takes many hours to bring about maximum recovery at this temperature.

CONCLUSIONS

Preliminary results indicate that significant recovery of output in electron irradiated AlGaAs cells can be achieved by thermal annealing. The onset of recovery appears to be between 125 and 200°C. Since silicon solar cells show little, if any recovery at these temperatures, these results are extremely encouraging. With AlGaAs cells, the problem of providing sufficient heat to the solar panel would be greatly reduced compared to a silicon solar cell panel.

Our data does not match the results obtained from the NTS-2 flight experiment. We observe recovery of short circuit current and open circuit voltage at temperatures greater than 125°C, while the flight data showed recovery of open circuit voltage and fill factor at $\sim$80°C. Our experiments provide no direct assistance in interpreting the puzzling information yielded by the NTS-2 flight experiment.

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AlGaAs ELECTRICAL PERFORMANCE AFTER 1×10^{15} e/cm^2

(5 SAMPLES EACH TEST)

Condition	I_{sc} (mA)	V_{oc} (mV)	P_{max} (mW)
$\phi = 0$	108.7	992	83.9
$\phi = 10^{15}$ (28°C)	94.6	899	68.5
125°C-15 hrs	94.2	901	68.5
$\phi = 0$	109.4	985	82.7
$\phi = 10^{15}$ (125°C)	94.9	899	68.3

TABLE 1

AlGaAs ELECTRICAL PERFORMANCE AFTER 1×10^{16} e/cm^2

(4 SAMPLES)

Fluence (e/cm^2)	I_{sc} (mA)	V_{oc} (mV)	P_{max} (mW)
$\phi = 0$	104.9	964	79.8
$\phi = 10^{15}$	92.4	887	64.9
$\phi = 10^{16}$	79.6	808	49.3

TABLE 2

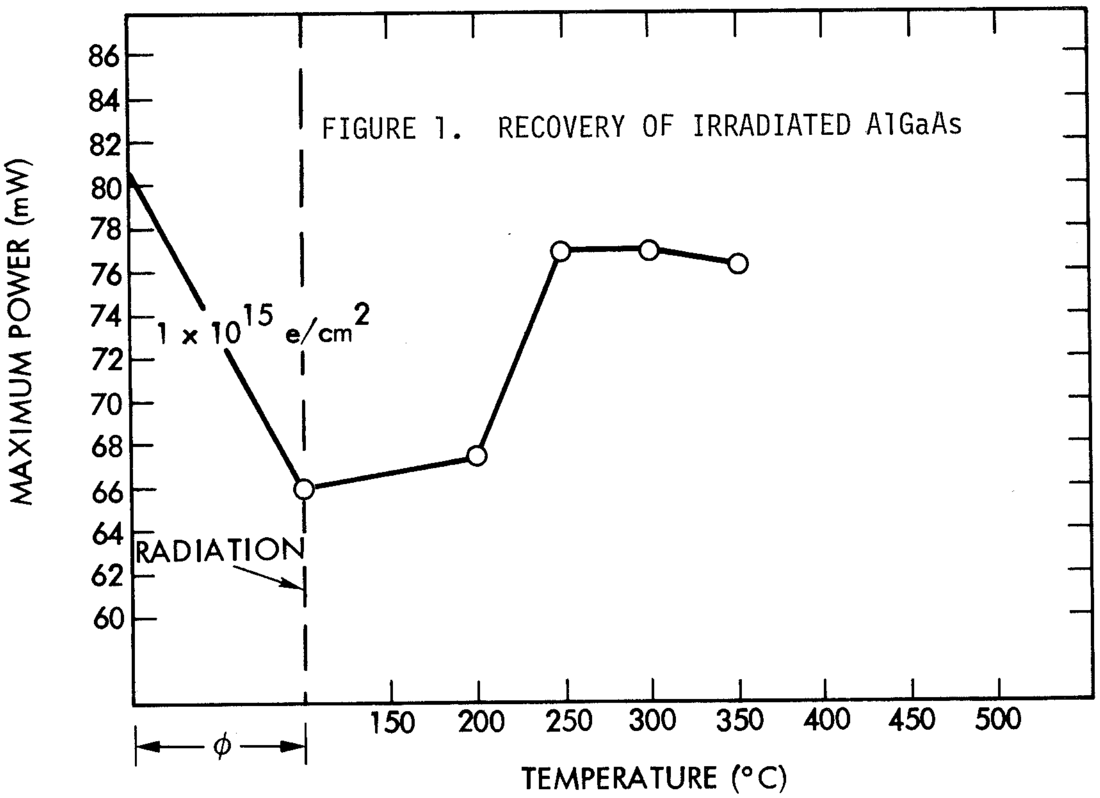

FIGURE 1. RECOVERY OF IRRADIATED AlGaAs

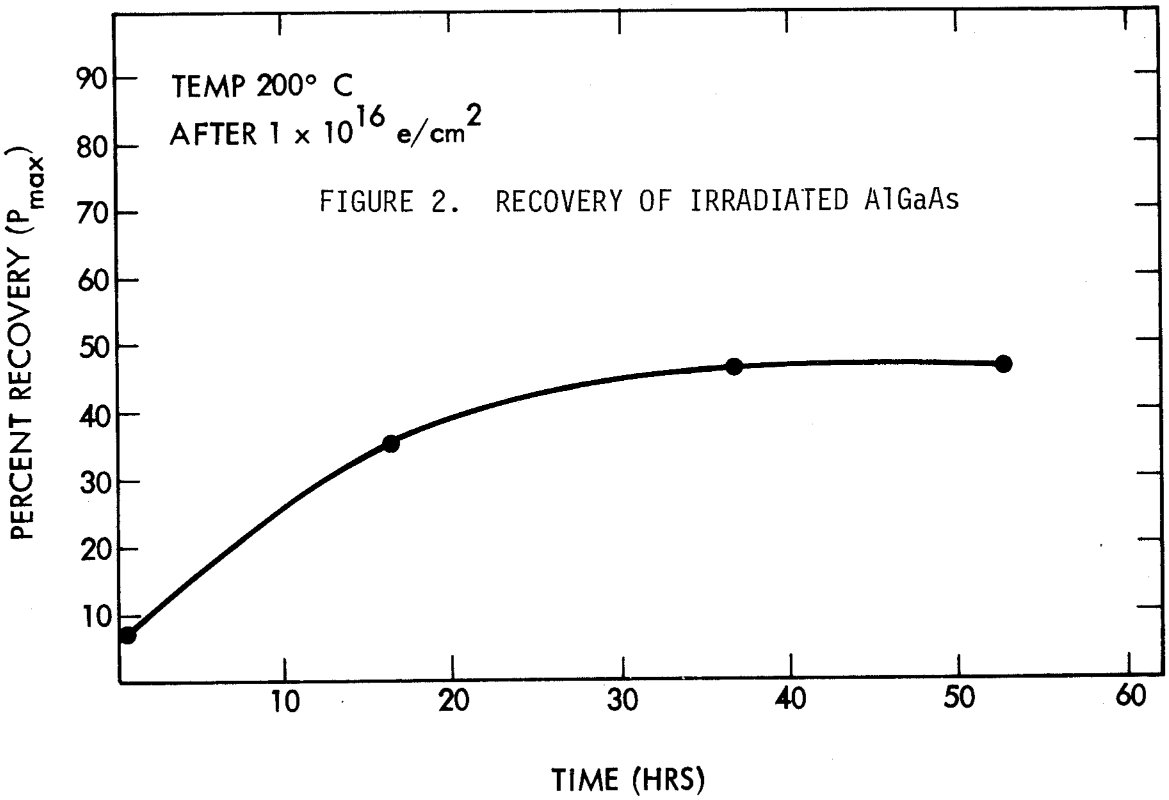

FIGURE 2. RECOVERY OF IRRADIATED AlGaAs