PROGRESS TOWARD THIN-FILM GaAs SOLAR CELLS USING A SINGLE-CRYSTAL Si SUBSTRATE WITH A Ge INTERLAYER*

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EXTENDED ABSTRACT

INTRODUCTION

The objective of our research program is to develop a technology for fabricating light-weight, high-efficiency, radiation-resistant solar cells for space applications. The approaches currently adopted are to fabricate shallow homojunction n^+/p as well as p/n AlGaAs-heteroface GaAs solar cells by organometallic chemical vapor deposition (OM-CVD) on single-crystal Si substrates using in each case, a thin Ge epi-interlayer first grown by CVD. This approach maintains the advantages of the low specific gravity of Si as well as the high efficiency and radiation-resistant properties of the GaAs solar cell which can lead to greatly improved specific power for a solar array. The intermediate goals of the program are to investigate the growth of single-crystal GaAs epilayers on Ge epi-interlayers on Si substrates and to develop related solar cell fabrication technology. This paper reports on our progress toward these intermediate goals.

EXPERIMENTAL

In the experiment involving the growth of a GaAs/Ge/Si structure, Ge epi-interlayers were first grown on (100) single-crystal Si substrates in a vertical quartz CVD reactor at 700-725°C with a growth rate of about 0.1 micrometer/min by pyrolysis of GeH_4 in a H_2 gas mixture. Subsequently, the growth of GaAs layers on the Ge epi-interlayer were conducted in a horizontal quartz CVD reactor at similar temperature range with a growth rate of about 0.2 micrometer/min by pyrolysis of trimethyl gallium (TMG) and arsine (AsH_3) in a H_2 gas mixture.

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In the development of the n^+/p GaAs shallow-homojunction baseline structure, GaAs p- and n-type layers were produced by alternately adding dimethylzinc and hydrogen sulfide, respectively, to the OM-CVD gas stream, as the dopants. The active p-layer, about 2 micrometers thick, was doped to $1\text{-}2 \times 10^{17}/\text{cm}^3$, whereas the n^+ layer about 40 nm thick was doped to $4 \times 10^{18}/\text{cm}^3$ for low sheet resistance. Electroplated gold was used for grid and back surface contact coating, and the anti-reflection coating was made by vacuum deposition of Sb_2O_3.

RESULTS AND DISCUSSION

During the last Conference here at NASA Lewis, we reported the first successful growth of thin epitaxial layers of GaAs by OM-CVD onto a Ge epi-interlayer which was in turn grown onto a (100) Si substrate, with all epi-growth done by the CVD process. The structures thus produced were smooth, bright and shiny. However, some stress-induced cleavage lines and a high surface micropit density (about $10^5/\text{cm}^2$) were observed by SEM and optical microscopy. The high micropit density of the GaAs films were a consequence of the initial high micropit density (about $6 \times 10^7/\text{cm}^2$) of the Ge epi-interlayer.

In order to improve the Ge surface for subsequent GaAs growth, pulsed laser annealing experiments were first conducted. A Nd:YAG laser system at the laboratories of the Lockheed Missiles and Space Systems Division, Sunnyvale, California was used for these annealing studies. Annealing experiments were performed on Ge/Si samples with energy densities ranging from 0.35 to 0.79 J/cm^2 with a pulse width of less than 150 ns at a wavelength of 1.06 micrometers. The results at low energy density (0.35 J/cm^2) showed that the annealed Ge epi-layer possessed a smoother surface morphology, but had a surface micro-pit density similar to the unannealed Ge films. On the other hand, at high energy density (0.79 J/cm^2), some surface damage was evident. The best results were obtained when a laser energy density of about 0.64 J/cm^2 was used. This led to a 10-fold reduction of the surface micropit density on the Ge layer from the original value of about $10^7/\text{cm}^2$ (Fig. 1) to a value of about $10^6/\text{cm}^2$ (Fig. 2) and a considerably smoother surface. Although the improvement in surface morphology of Ge is significant, the micropit density value was still too high. Therefore, experiments were conducted with the aim of improving surface morphology by modifying the Ge interlayer growth technique.

The following steps were taken to improve Ge-crystal growth: 1) improving the leak-tightness of the CVD Ge growth system, 2) reducing the surface boundary layer thickness during Ge film growth by modification of the reactor design, and 3) a more effective initial purging of the system to minimize residual O_2 and H_2O vapor contamination. Thus a reduction of surface micropit density by four orders of magnitude for the Ge interlayers was achieved. A photomicrograph (Fig. 3) of typical Ge/Si samples thus produced shows a surface micropit density corresponding to about $5 \times 10^3/\text{cm}^2$.

Subsequently, GaAs films were deposited on those improved Ge/Si samples by OM-CVD. When a Ge/Si sample with a 0.5-micrometer thick Ge interlayer was used as the substrate wafer, a smooth epi-GaAs film with low micropit density (less than $5 \times 10^3/\text{cm}^2$) and without cleavage lines, and having a large surface area (2cm x 2cm) can be made routinely by OM-CVD. A photomicrograph of such a GaAs/Ge/Si sample is shown in Fig. 4. This low micropit density value should be adequate for solar cell (and other) applications, in view of the fact that, typically, a good single-crystal GaAs exhibits similar values of surface etch-pit density.

In the development of the n^+/p shallow-homojunction GaAs baseline solar cell technology, further improvement in energy conversion efficiency has been achieved. The solar cell samples grown showed AMO efficiencies between 15% and 16%. Light I-V characteristics of the best cell with an area of 1 cm^2 is shown in Fig. 5. The AMO energy conversion efficiency for this GaAs solar cell measured at 28°C is about 16% using a Spectrolab model XT-10 AMO simulator. This efficiency value is comparable to that reported by others employing the same n^+/p shallow-homojunction GaAs solar-cell structure.[2] The AMO values of V_{oc}, J_{sc} and FF for this cell were about 0.99V, 26.6 mA/cm^2 and 0.81, respectively.

Fig. 1. SEM photomicrograph of a typical Ge film grown at 700°C on a (100) Si substrate, before laser annealing.

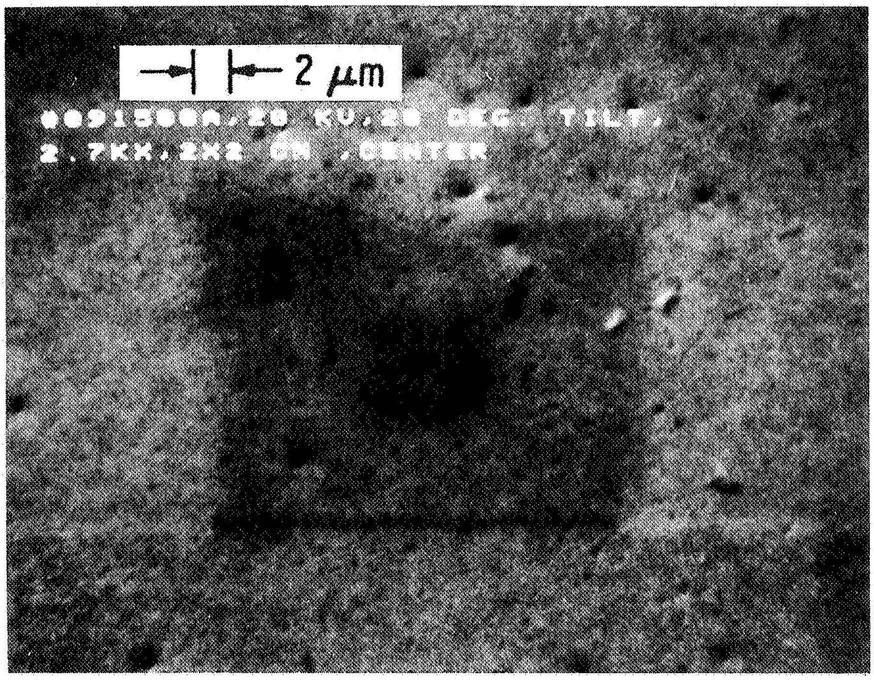

Fig. 2. SEM photomicrograph of the Ge/Si smaple annealed at an average energy-density of about 0.64 J/cm^2.

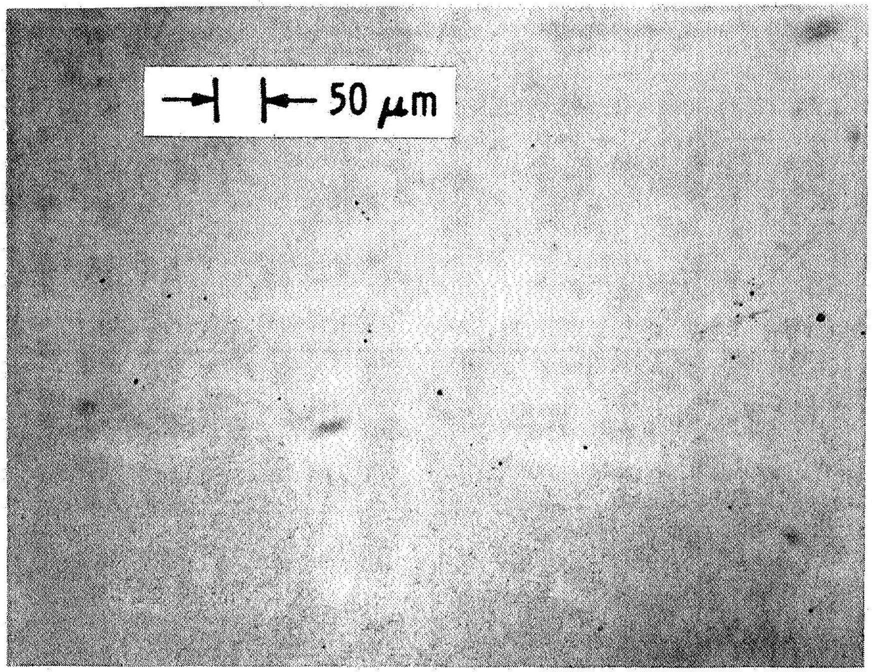

Fig. 3. Photomicrograph of a typical Ge film grown at 700°C on (100) Si substrate using the improved Ge-growth technology.

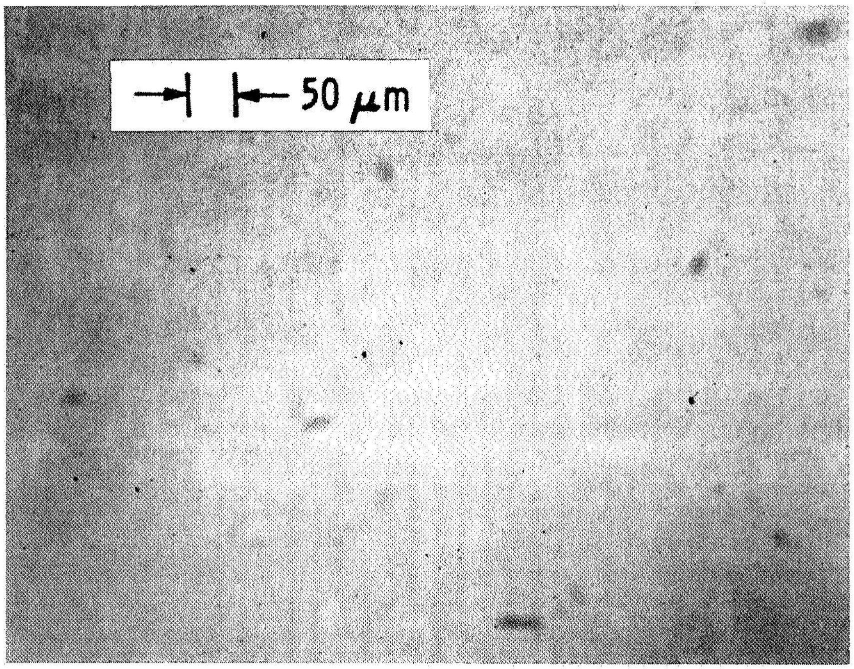

Fig. 4. Photomicrograph of a GaAs/Ge/Si sample with OM-CVD grown GaAs on a CVD-grown Ge interlayer.

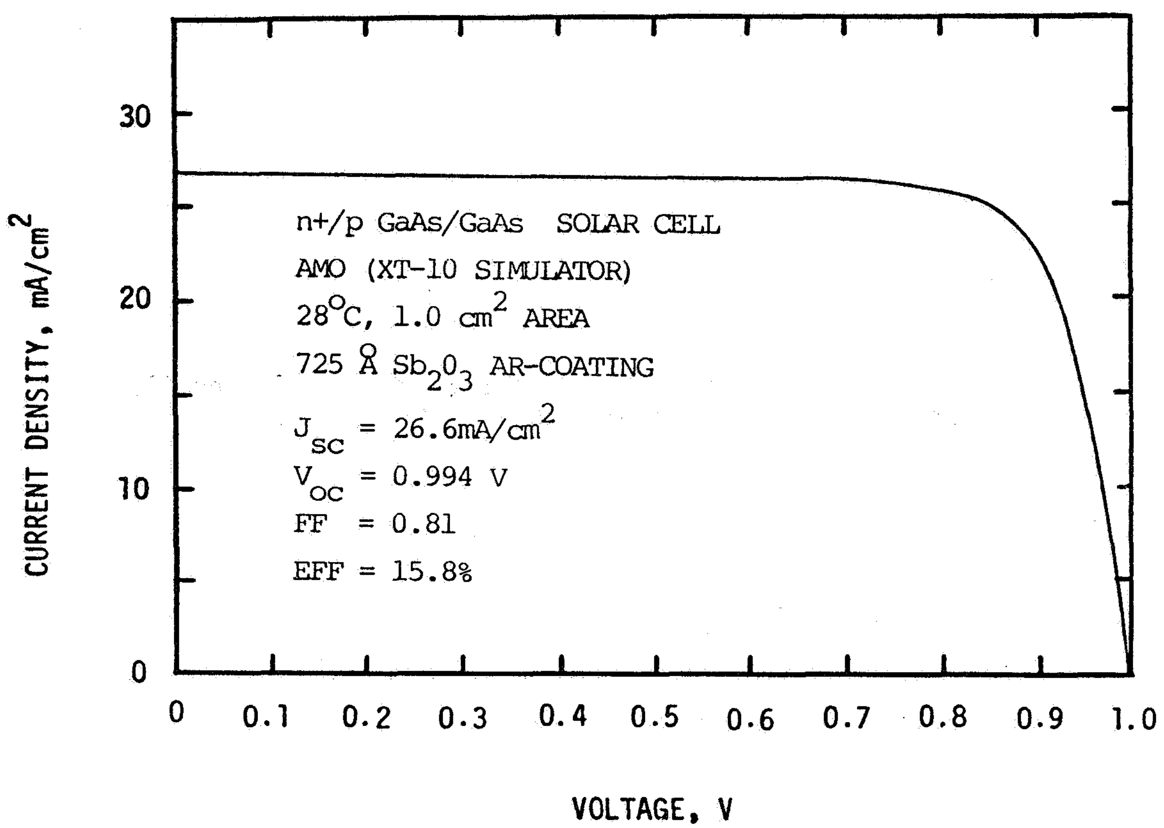

Fig. 5. Light I-V characteristics of a 1cm x 1cm - area n^+/p GaAs/GaAs solar cell.