Final
IN-44
034433

ZnSe WINDOW LAYERS For GaAs and $GaInP_2$ SOLAR CELLS

P9

Final Report

6/01/96 Through 5/31/97

NASA Grant NAG3-1881

Larry C. Olsen

ELECTRONIC MATERIALS LABORATORY
WASHINGTON STATE UNIVERSITY at TRI-CITIES
2710 University Drive
Richland, WA 99352

Tele: (509) 372-7221
FAX: (509) 372-7100

ABSTRACT

This report concerns studies of the use of n-type ZnSe as a window layer for n/p GaAs and $GaInP_2$ solar cells. Emphasis was placed in this phase of the project on characterizing the interface between n-type ZnSe films grown on epi-GaAs films grown onto single crystal GaAs. Epi-GaAs and heteroepitaxial ZnSe films were grown by MOCVD with a Spire 500XT Reactor. After growing epitaxial GaAs films on single crystal GaAs wafers, well-oriented crystalline ZnSe films were grown by MOCVD. ZnSe films were grown with substrate temperatures ranging from 250°C to 450°C. Photoluminescence studies carried out by researchers at NASA Lewis determined that the surface recombination velocity at a GaAs surface was significantly reduced after the deposition of a heteroepitaxial layer of ZnSe. The optimum temperature for ZnSe deposition appears to be on the order of 350°C.

1. INTRODUCTION

This report concerns the second phase of an investigation of ZnSe as a window layer for GaAs solar cells. GaAs solar cells are typically fabricated with $Al_xGa_{1-x}As$ (AlGaAs) heteroface layers. Since AlGaAs is well lattice matched to GaAs, a heteroface layer of AlGaAs can be grown on GaAs such that the surface recombination velocity at the AlGaAs/GaAs interface is relatively low. However, there are two particular problems with the use of AlGaAs. First, it is difficult to grow high quality Al containing compounds consistently because Al is so reactive with oxygen and water vapor. Another problem arises because it is preferable to grow AlGaAs at relatively high temperatures such as 800°C. Since an AlGaAs heteroface is grown after most of a cell structure has been formed, growth of AlGaAs can lead to interdiffusion effects that can degrade junction properties.

ZnSe is a potential replacement for AlGaAs since it has a bandgap of 2.67 eV and the lattice mismatch with GaAs is only 0.23 %. Furthermore, ZnSe can be grown at much lower temperatures than AlGaAs which may allow the fabrication of GaAs solar cells with improved current-voltage characteristics.

The ultimate objective of this work is to fabricate a n/p GaAs cell with an n-type ZnSe window layer. Work this second year has focused on characterizing ZnSe/GaAs interfaces . In particular, we have collaborated with researchers at NASA Lewis Research Laboratories to characterize ZnSe/GaAs interfaces with photoluminescence studies.

2. MOCVD GROWTH OF GaAs

Growth of GaAs is accomplished in a SPIRE 500XT reactor housed in the Electronic Materials Laboratory at WSU Tri-Cities by reacting trimethylgallium (TMGa) and arsine. N-type doping is achieved with Si as a dopant and with silane as the source of Si. This work has involved growth of ZnSe heteroepitaxial layers on GaAs wafers directly, and on GaAs epitaxial layers grown on Sumitoma wafers. A typical run profile is described by Figure 1. First, a nucleation layer of GaAs is grown at 625 °C and a growth rate of approximately 2 Å/s. Most of the epitaxial layer is then grown at 780°C.

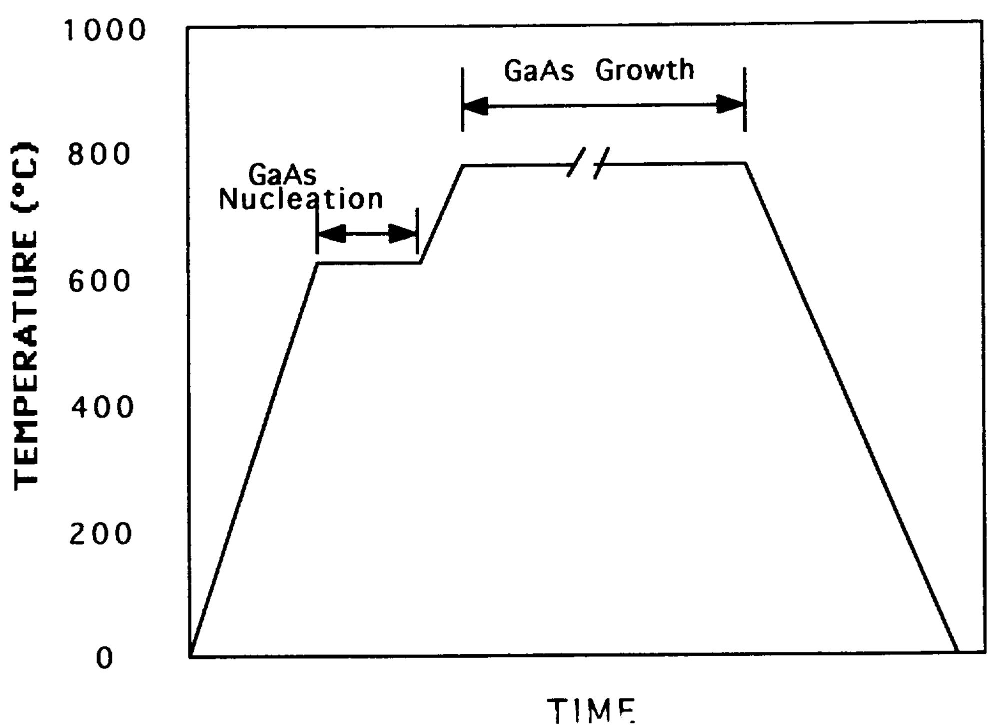

Figure 1. Temperature vs Time for growth of N-type GaAs on GaAs substrates

3. HETEROEPITAXIAL GROWTH OF ZnSe WINDOW LAYERS

Heteroepitaxial layers of ZnSe were grown epitaxial GaAs films of GaAs with a range of growth conditions and doping concentrations. ZnSe films were grown by MOCVD by reacting a zinc adduct with hydrogen selenide. ZnSe films were doped with both iodine and boron. The zinc adduct is formed (by a vendor) by reacting triethylamine (TEN) and dimethylzinc (DMZn). The triethylamine is mixed to give a vapor pressure of 16 torr at 20°C. Growth rate of ZnSe is controlled by adjusting the flow of hydrogen through a metalorganic bubbler. The growth rate varies linearly with the flow of hydrogen through the DMZn/TEN bubbler. Typical growth conditions that result in a ZnSe growth rate of 1 Å/s and a VI/II ratio of 5 are as follows: a total pressure of 65 torr, 6000 sccm of palladium-diffused hydrogen; 25 sccm hydrogen bubbled through the DMZn/TEN bubbler at 20°C; and 270 sccm hydrogen selenide (1% in H_2); and a substrate temperature of 250°C. Substrates are placed on a pancake shaped, SiC-coated graphite susceptor which is heated by RF induction. All gas flows and RF power are computer controlled. Although substrate temperatures were varied from 250°C to 450°C, most ZnSe films were grown at 350°C.

4. CHARACTERIZATION OF ZnSe/GaAs INTERFACE

Structures with ZnSe films grown on GaAs substrates were provided to NASA Lewis Research Center for photoluminescence (PL) studies. PL studies were carried out at both room temperature and at 4°K using the 488 nm line of an argon ion laser for excitation. Other details of the measurement were reported in Reference 1. Best results were obtained with ZnSe films grown at 350°C on epitaxial GaAs. Typical thicknesses of the heteroepitaxial ZnSe films were 800 Å while the epitaxial GaAs films were on the order of 1.0 μm. Figure 2 shows the room temperature PL spectrum for an epitaxial n-GaAs sample with and without a ZnSe heteroface. Since the absorption of the incident 488 nm light is negligible, the increase in PL signal is essentially due to a reduction in surface recombination velocity.

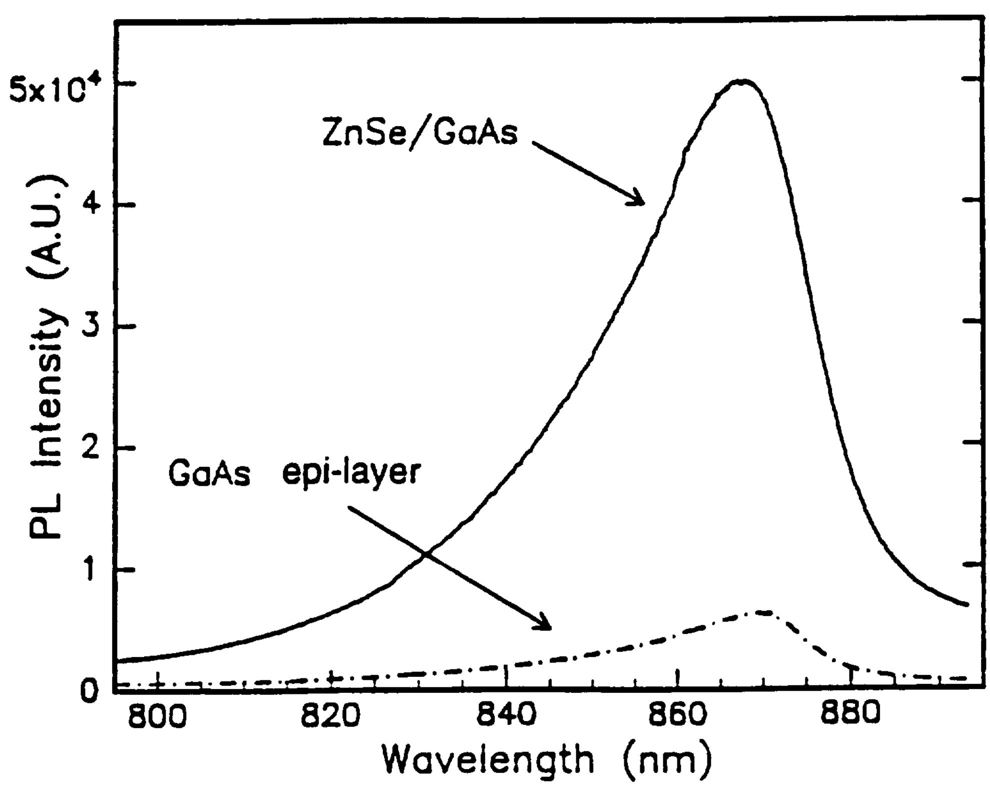

Figure 2. Room temperature PL spectrum of epi n-GaAs sample with and without a ZnSe heteroface (Taken from Reference 1).

As indicated above, best results were achieved with ZnSe films grown at 350°C. Table 1 compares PL intensities for three samples, a bare epi-GaAs film, and ZnSe/epi-GaAs structures with the ZnSe films grown at 300°C and 350°C. The surface recombination velocity is reduced much more for structure with ZnSe heteroface grown at 350°C. Apparently, ZnSe films grown at 350°C yield a better interface than those with ZnSe films grown at 300°C.

One other area examined by the researchers at NASA concerned interpretation of PL results obtained at temperatures in the range of 4°K to 90°K. When samples were illuminated with a 455 nm argon laser wavelength, where some absorption occurs in ZnSe, no PL features in addition to those attributed to GaAs were detected. There are two possible explanations: (1) The interband density at the ZnSe/GaAs interface was very low, or (2) band bending occurred at the interface such that minority carrier confinement was achieved. In either case, this result was consistent with the observed reduction in SRV by the ZnSe heteroface compared to bare epi-GaAs surfaces.

TABLE 1 — PL Intensity Of WSU Test Structure Measured By NASA

SAMPLE	CORRECTED PL SIGNAL
Epi-GaAs	13,600
300 Å ZnSe/Epi-GaAs Grown At 300°C	26,200
800Å ZnSe/Epi-GaAs Grown At 350°C	72,000

5. APPLICATION TO GaAs N/P SOLAR CELLS

The ultimate objective of this work is to fabricate n/p GaAs solar cells with n-type ZnSe heterofaces. The expected band structure for such a structure is depicted by Figure 3. Although one expects a small band discontinuity to exist in the conduction band (on the order of 20 mV), the photocurrent should not be affected. If further work is conducted, it is anticipated that solar cell structures will be fabricated in collaboration with NASA Lewis Research Laboratories. If time permits, heterofaces based on $ZnSe_xS_{1-x}$ will also be examined.

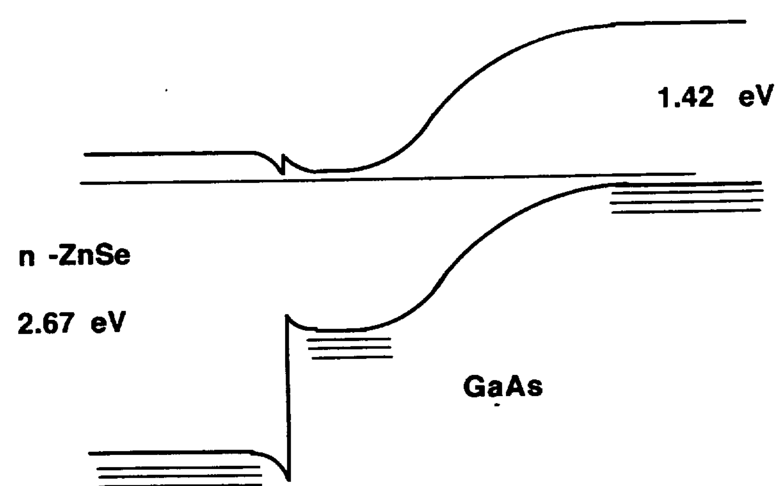

Figure 3. Band diagram for n/p GaAs solar cell with a n-type ZnSe heteroface.

6. CONCLUSIONS

ZnSe heteroface layers grown on n-type GaAs epilayers by MOCVD have been shown to greatly reduce the surface recombination velocity relative to the bare epi-GaAs surface. The optimum substrate temperature for ZnSe growth was demonstrated to be approximately 350°C. Thus, the possibility of n-ZnSe heterofaces grown by MOCVD at relatively low temperatures for GaAs n/p solar cells has been demonstrated.

REFERENCES

1. J.A. Yater, G.A. Landis, S.G. Bailey, L.C. Olsen and F.W. Addis, "ZnSe Window Layers For GaAs Solar Cells," Twenty-Fifth IEEE PVSC, 1996, pp. 65-68.