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ELECTRICAL PROPERTIES OF Mg-IMPLANTED GaAs ENCAPSULATED BY As-DOPED a-Si:H FILMS.

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GaAs implanted with 100 keV Mg ions at doses of $5x10^{13}$-$1x10^{15}$ cm^{-2} was encapsulated with As and un-doped a-Si:H films with a thickness of about 80 nm. The sheet carrier concentration in As-doped a-Si:H encapsulated samples was higher than that in un-doped a-Si:H encapsulated samples. The sample which was capped with the a-Si:H film with $2x10^{20}$ cm^{-3} of As and annealed at 800°C had a high sheet carrier concentration of $3x10^{14}$ cm^{-2}.

1. INTRODUCTION

Magnesium as a p-type dopant is currently popular for implantation in GaAs. There is a problem because of the fast dopant diffusion during high temperature anneal necessary to remove the implantation damage. Special precautions must be taken for the anneal of compound semiconductors such as GaAs that the material decomposes at relatively low temperatures. The surface is capped with an encapsulant to prevent the decomposition. A low-temperature plasma-enhanced chemical-vapor deposition (PECVD) a-Si:H film can be used as an encapsulant.[1)] The a-Si:H film however crystallized during annealing at temperatures above 600°C. The GaAs surface dissociated remarkably through grain boundaries of poly-Si. The crystallization can be inhibited by doping a-Si:H with As.[2)] In this paper, we report that the activation efficiency of Mg implanted into GaAs could be improved using a As-doped a-Si:H film as an encapsulant for high temperature annealing.

2. EXPERIMENTAL METHODS

Un-doped semi-insulating, LEC-grown (100) GaAs wafers were implanted with 100 keV Mg ions in an off-channel direction at room temperature at doses of $5x10^{13}$-$1x10^{15}$ cm^{-2}. Approximately 80 nm of PECVD As- and un-doped a-Si:H films was deposited on the surface of the Mg-implanted GaAs wafer at 250°C. The a-Si:H films were doped with As ranging from $6x10^{18}$ to $2x10^{20}$ cm^{-3}; we gave a name of Film-0 for the a-Si:H film without As; Film-1 for the a-Si:H film with As of $6x10^{18}$ cm^{-3}; Film-2 for the a-Si:H film with As of $4.5x10^{19}$ cm^{-3}; Film-3 for the a-Si:H film with As of $2x10^{20}$ cm^{-3}. The concentration of As in the a-Si:H encapsulant was measured using an atomic absorption spectrophotometer. The sample was located between two Si wafers, and was then annealed in a flow of Ar gas at 700 - 900°C for 15 min.

3. RESULTS

3.1. Electrical activation

Figure 1 is a plot of the sheet carrier concentration vs. implant dose for Mg implanted GaAs encapsulated with Film-0 or Film-3. The sheet carrier concentration in the samples encapsulated with Film-0 was smaller than that encapsulated with Film-3 for all the annealing temperature and all the implant dose. That is, on Film-3/GaAs annealed at 800°C, the activation efficiency was about 41 % for an implant dose of $1 \times 10^{15} cm^{-2}$, which went up to about 82 % for $1 \times 10^{14} cm^{-2}$. On the other hand, on Film-0/GaAs annealed at 800°C , the activation efficiency was about 8.5 % for an implant dose of $1 \times 10^{15} cm^{-2}$, which went up to about 24 % for $1 \times 10^{14} cm^{-2}$. The annealing temperature required for the maximum activation efficiency in this experiment was slightly higher than that of Mg-implanted GaAs encapsulated with an 70 nm layer of Si_3N_4.[3] The activation efficiency was about twice that obtained by Choe et al.[3] The sheet carrier concentration increased with an increase in the implant dose for all the annealing temperature but the activation efficiency decreased with the implant dose as described above.

Figure 2 shows the depth profiles of the carrier concentration for samples, which were implanted with 100 keV Mg ions at a dose of $1 \times 10^{15} cm^{-2}$ and subsequently was annealed at 800°C by encapsulating with As-doped a-Si:H films. The LSS theory predicts that the peak concentration occurs at a depth of 0.095 μm for an ion energy of 100 keV and is $1.8 \times 10^{20} cm^{-3}$ for an implant dose of $1 \times 10^{15} cm^{-3}$. It can be clearly seen from the figure that the carrier concentration profiles are highly dependent upon the concentration of As-doped in the a-Si:H encapsulant: the peak carrier concentration increases with an increase in the concentration of As and the position that the carrier concentration decreases abruptly with depth became shallower.

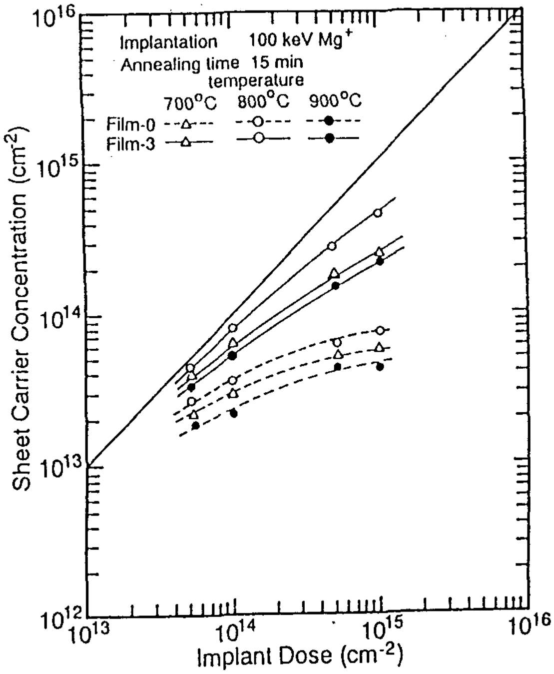

Fig.1. The sheet carrier concentration of Mg-implanted GaAs.

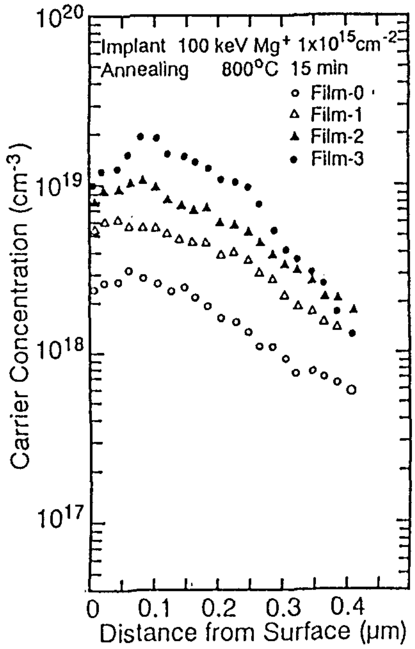

Fig.2. Depth profiles of the carrier concentration for samples, which were implanted with 100 keV Mg^+ ions at a dose of $1 \times 10^{15} cm^{-2}$ and subsequently was annealed

3.2. AES study

Figure 3 shows the depth profiles of the yields of the 92 eV Si, the 1229 eV As and the 1070 eV Ga AES signal obtained on GaAs wafers encapsulated with Film-0, Film-1, Film-2 or Film-3. The samples were annealed at 850oC for 15 min. The yields of the AES signals were obtained by dividing the measured peak height with the sensitivity factor (S). Here, the value of S used was 0.46 for Si atoms, 0.45 for Ga atoms and 0.18 for Si atoms.

The depth profile of the yields of AES signals on as-deposited Film-0/GaAs structure was similar to that on Film-3/GaAs structure. By comparing the depth profile of the yield of the AES signals between the as-deposited and the annealed Film-0/GaAs structure, we find that Si was diffused from the un-doped a-Si:H film into deep side of the GaAs wafers during annealing and also Ga and As were outdiffused into the

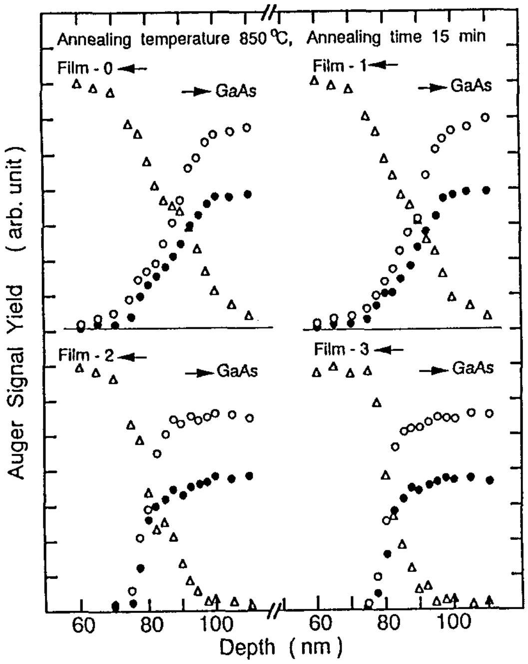

Fig.3. The depth profiles of the yields of the 92 eV Si, the 1229 eV As and the 1070 eV Ga AES signal on Film-0/GaAs, Film-1/GaAs, Film-2/GaAs and Film-3/GaAs structures annealed at850°C for 15 min.

Film-0. The slopes of the As, the Ga and the Si AES signal yield vs. depth plots in the neighborhood of the interface became steeper with an increase in the concentration of As in the a-Si:H films. The As and the Ga AES signals at a position in the a-Si:H films, at which the 92 eV Si AES signal began to decrease, decreased with an increase in the concentration of As in the a-Si:H film. That is, the outdiffusion of As and Ga from GaAs into a-Si:H was reduced with an increase in the As concentration in the a-Si:H encapsulant.

Film-1 on GaAs wafers crystallized at the approximately same temperature as Film-0 on GaAs.[4] Film-1 has an lower concentration of As than $7\times10^{18}\ cm^{-3}$ in the as-deposited Film-1. However, the intermixing of chemical species between a-Si:H and GaAs on the Film-1/GaAs structure was smaller than the Film-0/GaAs structure. That is, the doped As atoms served effectively to suppress the intermixing of the chemical species between a-Si:H and GaAs even if the concentration of As in the a-Si:H films was less. The concentration of As in Film-1 was much less than the solid solubility limit about $1\times10^{21}\ cm^{-3}$ at 850°C[5] of As in c-Si.

The intermixing zone on the Film-2/GaAs and the Film-3/GaAs structures were narrower than that on the Film-1/GaAs structure. The concentrations of As in Film-2 and Film-3 were $5\times10^{19}\ cm^{-3}$ and $2\times10^{21}\ cm^{-3}$, respectively, which is lower than the solid solubility of As in c-Si. Film-2 and Film-3 on GaAs recrystallized at 850°C.[4] The intermixing on the Film-2/GaAs and the Film-3/GaAs structures was suppressed, in contrast to the Film-1.

4. DISCUSSION

Interdiffusion of chemical species occurs at the interface when a-Si:H/GaAs structures are treated at high temperatures: Si diffuses into GaAs. A number of As and Ga vacancies is also introduced in the region near the GaAs surface. The diffusivity of the As vacancy (V_{As}) in GaAs is about seven times lower than that of the Ga vacancy (V_{Ga}) at 800°C.[6] An As vacancy rich region is formed in a region near the surface and the Ga vacancy diffuses deeper than the As vacancy if there are no chemical reaction between the As and Ga vacancies. The amphoteric impurity Si in GaAs has several possible sites such as Si_{Ga}^+, Si_{As}^-, Si_{Ga}^+-Si_{As}^-, Si_{Ga}^+-V_{Ga}^-, and Si_{As}^--V_{As}^+. Substitutional Mg forms a complex by reacting with V_{As}^+ or Si_{Ga}^+ and is rendered inactive. Such the complexes are Mg_{Ga}^--Si_{Ga}^+ and Mg_{Ga}^--VAs+. Since the Fermi level is pulled down toward the valence band by doping with Mg, the concentration of V_{Ga}^- decreases and the concentration of V_{As}^+ increases. As a result, the probability of the formation of Si_{As}^--V_{As}^+ and Mg_{Ga}^--V_{As}^+ becomes higher with an increase in the concentration, and that of Si_{Ga}^+-V_{Ga}^- complexes becomes lower. The SiAs--VAs+ and Mg_{Ga}^--V_{As}^+ are dominant complex in the region near the surface. Thus, the carrier concentration can be decreased in the As vacancy rich region near the surface.

The formation of electrically inactive complexes such as Si_{Ga}^+-V_{Ga}^-, Mg_{Ga}^--Si_{Ga}^+ and Mg_{Ga}^--V_{As}^+ is possible in the deep side of GaAs in which the Ga vacancy is rich. The concentration of Mg_{Ga}^--Si_{Ga}^+ is high in the deeper region, compared with the surface region. The concentration of V_{As}^+ also increases since the Fermi level is pulled down toward the valence band by doping with Mg. The activation efficiency of the implanted Mg can be decreased since the concentration of the complex increases with an increase in the concentration of the Ga and As vacancy or the concentration of implanted Mg.

5. CONCLUSION

Intermixing of the chemical species between a-Si:H encapsulants and GaAs can be retarded with an increase in the concentration of As in the a-Si:H encapsulant. Most of As and Ga vacancies are induced in the GaAs surface. Most of Si also are induced in the GaAs surface. An As vacancy rich region is formed in the surface region and the Ga vacancy diffuses in the deeper side of GaAs since the diffusivity of the As vacancy in GaAs is much lower than that of the Ga vacancy. Si is possible for both Ga and the As sites. The concentrations of Ga and As vacancies decreased with an increase in the concentration of As in the a-Si:H encapsulant. The implanted Mg can form electrically inactive complexes by reacting with Si atoms, Ga and As vacancies induced into GaAs. Thus, the activation efficiency of the implanted Mg also increased with an increase in the concentration of As in the a-Si:H encapsulant

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