Extended Abstracts of the 1994 International Conference on Solid State Devices and Materials, Yokohama, 1994, pp. 181-183 **PB-2-1**

A Novel Surface Passivation Scheme for Compound Semiconductor Using Silicon Interface Control Layer and Its Application to Near-Surface Quantum Wells

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The recently proposed novel passivation scheme using a structure of SiO_2/ultra thin silicon interface control layer (Si ICL)/compound semiconductor was father improved by addition of ultra thin silicon nitride and applied to passivation of near-surface quantum wells. Processing sequence for the improved structure was characterized and optimized with the use of *in-situ* XPS and C-V techniques. The improved passivation scheme was applied to passivation of near-surface $Al_{0.3}Ga_{0.7}As$ /GaAs(80Å)/$Al_{0.3}Ga_{0.7}As$ quantum wells, leading to recovery of PL intensity.

1. INTRODUCTION

Since surfaces and interfaces play far more important role in the quantum structures than in the present-day devices, surface passivation is a critical issue for their successful utilization. However, compound semiconductor surfaces and interfaces are known to posses high density of surface states which cause so-called Fermi level pinning phenomenon[1]. Some of the recent experiments involving compound semiconductor quantum structure already indicate importance of surface states, showing presence of side-gating phenomena in GaAs quantum wires[2], and presence of undesirable interaction of confined quantum states and surface states takes place in near-surface quantum wells (QWs) [3-5].

Based on disorder induced gap states (DIGS) model[1], we have recently proposed a novel passivation scheme in which an ultra thin silicon interface control layer (Si ICL) is inserted between compound semiconductor and outer insulator. The new scheme has been successfully applied to fabrication of InGaAs MISFETs[6] and photoconductive detectors[7]. However, a photo-excited chemical vapor deposition (CVD) SiO_2 layer[8,9] was used as the outer insulator in our original approach and this was found to be a cause of poor reproducibility due to uncontrollable deep penetration of photo-excited oxygen radical.

The purpose of this paper is to further improve the novel passivation scheme with use of CVD silicon nitride and to apply the scheme to the compound semiconductor quantum structures. The process details and x-ray photo electron spectroscopy (XPS) and electrical characterization of the new scheme are presented together with its successful application to passivation of near-surface QWs.

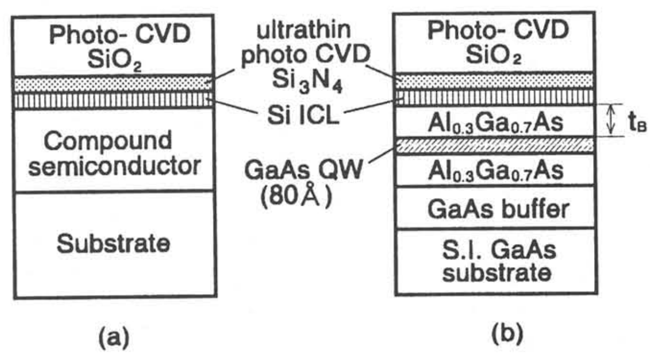


Fig. 1 (a) Basic structure of novel passivation scheme and (b) its application to a near-surface QW.

2. EXPERIMENTAL

The improved structure of the novel passivation scheme is shown in **Fig. 1(a)**. Process optimization was mainly done choosing InGaAs with a high lattice mismatch with silicon as the compound semiconductor. The new structure possesses an additional a ultra thin Si_3N_4 layer which acts as an effective barrier preventing direct chemical reaction between the Si/InGaAs structure and the excited oxygen radicals. Passivated structures were fabricated using a ultra high vacuum (UHV)-based integrated fabrication system where MBE, photo-CVD, XPS and other chambers are connected by UHV-transfer chamber. First, n-type $In_{0.53}Ga_{0.47}As$ layer was grown by MBE on n^+-InP (100) substrate. Then, ultra thin Si ICL was formed at the substrate temperature of 250°C by MBE using Si Knudsen-cell. Finally, an ultra thin photo-CVD Si_3N_4 layer was deposited, using gas mixture of SiH_4, NH_3, Ar and N_2, and ArF excimer laser (193nm), followed by outer thick photo-CVD SiO_2 layer, using gas mixture of SiH_4, N_2O

and Ar. All samples were annealed in hydrogen atmosphere for 1 hour at the temperature of 350°C. To characterize and optimize the interface between passivation layer and semiconductor, XPS and capacitance-voltage (C-V) measurements were made.

Then, optimized passivation process was later applied to a near-surface GaAs /$Al_{0.3}Ga_{0.7}As$ QW structure on semi-insulating (S.I.) GaAs (100) substrate shown in **Fig. 1(b)**. All the layers were undoped. To characterize the effect of the present passivation scheme for quantum structure, PL measurements at 77K were made by changing the thickness t_B of the top AlGaAs barrier layer and comparing passivated and unpassivated structures. Ar^+ laser (514.5nm) was used as excitation with a constant excitation intensity of 1W/cm^2. The thickness t_B was successively decreased using chemical etching by a solution of $C_6H_8O_7$:H_2O_2 in the volume ratio 1:1. Etching rate was determined to be 15Å/min by step-height atomic force microscopy (AFM) measurements of partially masked calibration samples.

3. IMPROVEMENT OF PASSIVASION SCHEME BY ULTRA THIN NITRIDE

The effect of deposition of photo-CVD Si_3N_4 on the ultra thin Si ICL was investigated by *in-situ* XPS measurements. **Figure 2** shows dependence of the integrated intensity ratio defined by I(Si2p in silicon crystal) /I(Ga3p in InGaAs) on the initial thickness of Si ICL for two structures shown in the inset. For large initial thickness of Si ICL, the slope of two curves from before and after deposition are nearly same, indicating that only a thickness of about a 5Å of Si ICL is changed into nitride during deposition which much smaller than the case of SiO_2 deposition. On the other hand, thickness reduction becomes even smaller for smaller Si ICL thickness, leaving monolayer silicon.

Results of *in-situ* XPS analysis of the InGaAs surface are compared in **Fig. 3**, for SiO_2/InGaAs (a) and SiO_2/Si_3N_4/Si/InGaAs (b) structures. Direct deposition of SiO_2 leads to severe selective oxidation of gallium on the InGaAs surface. However, oxidation and nitridation of the InGaAs surface are completely suppressed with the improved passivation structure.

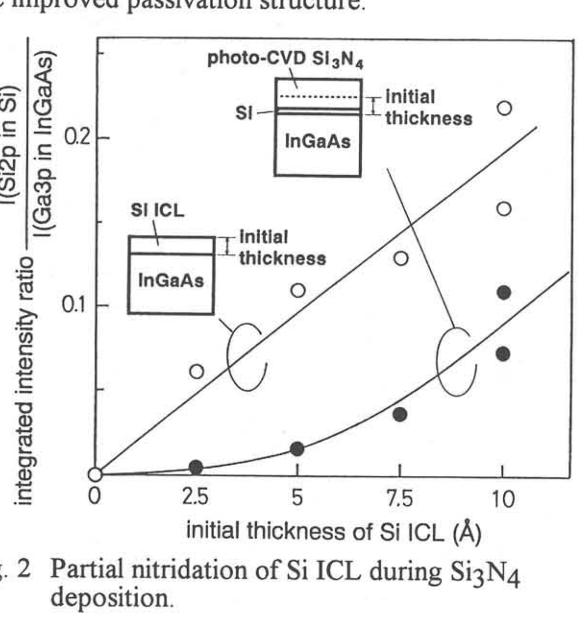


Fig. 2 Partial nitridation of Si ICL during Si_3N_4 deposition.

To characterize the electrical properties of the interface at insulator - semiconductor (I-S), C-V

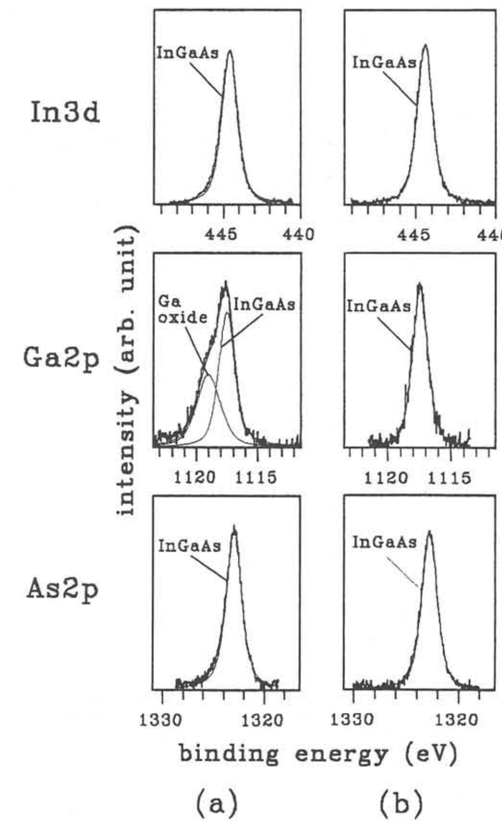


Fig. 3 XPS analysis of InGaAs surface composition between direct deposition of SiO_2 and the present scheme.

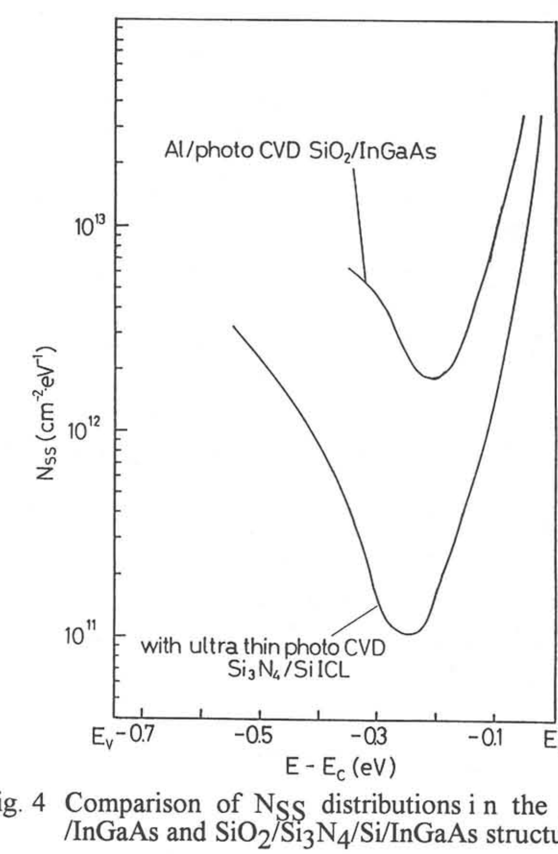


Fig. 4 Comparison of N_{SS} distributions i n the SiO_2 /InGaAs and SiO_2/Si_3N_4/Si/InGaAs structures.

measurements were made for complete metal-insulator-semiconductor (MIS) structure. Interface state density (N_{SS}) distributions calculated from 1MHz C-V curves of SiO_2/InGaAs and SiO_2/Si_3N_4/Si/InGaAs structures

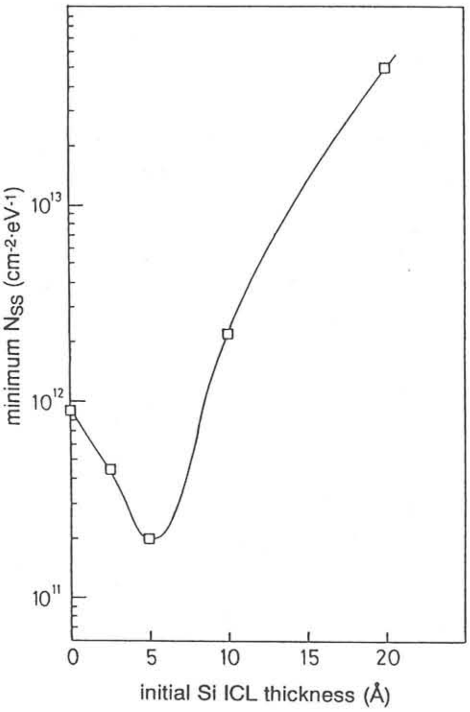
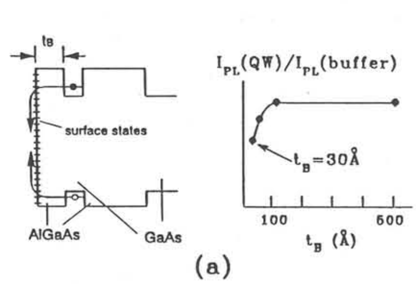


Fig. 5 Dependence of N_{SS} minimum on the initial Si ICL thickness.



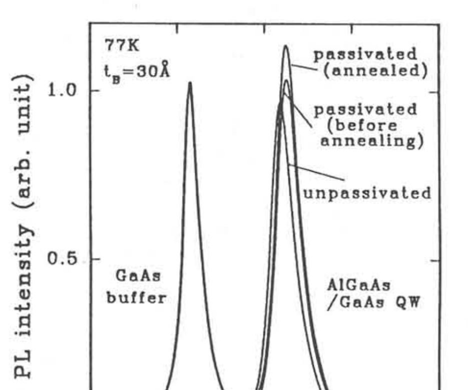


Fig. 6 Application to near-surface QWs. (a) Reduction of QW PL intensity due to surface states and (b) effect of passivation.

are compared in **Fig. 4**. Tow curves show the U-shaped continuous distribution of N_{SS}. However, a great deal of reduction of N_{SS} takes place in the present passivation structure as compared with the structure formed by direct deposition of SiO_2. Dependence of N_{SS} minimum on the initial Si ICL thickness is shown in **Fig. 5**. With the optimum thickness of 5Å, N_{SS} minimum of $2x10^{11}cm^{-2}\cdot eV^{-1}$ was obtained. For smaller initial thickness of Si ICL, N_{SS} is large due to direct nitridation of InGaAs surface, and for larger thickness, N_{SS} again increased due to generation of misfit dislocations.

4. PASSIVATION OF NEAR-SURFACE QWs

The present passivation scheme was applied to near-surface AlGaAs/GaAs QWs shown in **Fig. 1(b)**. With reduction of the top barrier thickness t_B of an $Al_{0.3}Ga_{0.7}As$/GaAs(80Å)/$Al_{0.3}Ga_{0.7}As$ by successive chemical etching, QW PL intensity normalized by PL intensity from GaAs buffer layer reduced as shown in **Fig. 6(a)** with a gradual small red shift of PL peak. According to Moison et al.[3], this is caused by interaction of confined QW states and surface states. However, remarkable recovery of PL intensity and PL peak position was observed by application of the present passivation scheme on barrier surface as shown in **Fig. 6(b)**. With addition of annealing process, PL intensity from QW are increased. These are consistent with the reduction of surface states.

5. CONCLUSION

An attempt was made to improve the novel Si ICL based passivation scheme using an ultra thin silicon nitride as a barrier of direct chemical reaction. An *in-situ* XPS characterization was used to optimize the present passivation scheme. Then, the present passivation scheme was successfully applied to passivation of near-surface AlGaAs/GaAs QWs.

REFERENCES

1) H. Hasegawa and H. Ohno: J. Vac. Sci. Technol., **B4**, 1130 (1986).
2) Y. Feng, T.J. Thornton, J.J. Harris and D. Williams: Appl. Phys. Lett., **60**, 94 (1992).
3) J. Moison, K. Elcess, F. Houzay, J.Y. Marzin, J.M. Gérard, F. Barthe and M. Bensoussan: Phys. Rev. B, **41**, 12945 (1990).
4) Y.-L. Chang,I-H. Tan, Y.-H. Zhang, J. Merz, E. Hu, A. Forva and V. Emiliani: Appl. Phys. Lett., **62**, 2697 (1993).
5) Z. Sobiesierski, D.I. Westwood, D.A. Woolf, T. Fukui and H. Hasegawa: J. Vac. Sci. & Technol., **B11**, 1723 (1993).
6) M. Akazawa, H. Hasegawa and E. Ohue: Jpn. J. Apll. Phys., **28**, L2095 (1989).
7) K. Iizuka, I. Akasaka, T. Tsubata and H. Hasegawa: Proc. of 1989 Int. Symp. GaAs and Related Comp., Karuizawa, (IOP publishing Ltd., Bristol, 1990).
8) H. Hasegawa, M. Akazawa, H. Ishii and K.Matuzaki: J. Vac. Sci. & Technol., **B7**, 870 (1989).
9) M. Akazawa, H. Ishii and H. Hasegawa: Jpn. J. Apll. Phys., **30**, 3744 (1991).