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Electrical Properties of Gallium Fluoride (GaF_3)/GaAs Interface with and without Sulfur Treatment

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The interface properties of Gallium Fluoride (GaF_3) deposited on GaAs have been investigated, for the first time. It is shown that the properties are good enough to generate inversion carriers either when a GaF_3 is deposited onto a homoepitaxial GaAs layer without breaking the vacuum or when the film is deposited on a sulfur treated surface. The latter process, which was found to be quite effective to reduce the interface states generated by air exposure of GaAs surface, will give more freedom in fabricating GaAs MIS devices.

1. Introduction

Although the importance of GaAs is not anymore to be proved, defect induced non ideal surfaces and interfaces still present obstacle to the potential applications of GaAs in very high speed and low power consumption integrated circuits. Unfortunately, the problem lies in the fact that near ideal surfaces rapidly degrade when exposed to oxygen so that a passivating surface layer is needed for good device performance. Different solutions have been proposed as for example the successive growth, without breaking the vacuum, of a homoepitaxial layer on GaAs and an insulator [1, 2].

Among the various approaches , the $(NH_4)_2S_x$ treatment has been found to be very effective in improving the surface/interface electronic properties of GaAs [3]. After the treatment, the choice of the insulator and its deposition process is of primary importance. A soft process is required so that the GaAs surface is not altered during the deposition of the insulator. The candidate except from a high resistivity and breakdown strength should have a negligible density of deep level interfacial and bulk traps. Moreover, when it is chemically bonded to the semiconductor, it should not create interfacial charges, which would cause an additional band bending in the semiconductor. Recently[4], the Gallium Fluoride (GaF_3) has been found to show some interesting properties. The main known characteristics of GaF_3 are summarized in the following table [5]:

PROPERTIES OF GAF_3

Molecular weight	126.72
Density	4.48 g/cm^3
Melting point	1000℃
Crystalline structure	Trigonal
Lattice parameter	a: 5.20 Å ; α = 57.7°
Solubility	$2x10^{-6}$ g/cm^3

In this paper, we investigate for the first time, the interface properties of GaF_3 films deposited on GaAs and show that the properties are good enough to generate inversion carriers either when a GaF_3 film is deposited onto a homoepitaxial GaAs layer

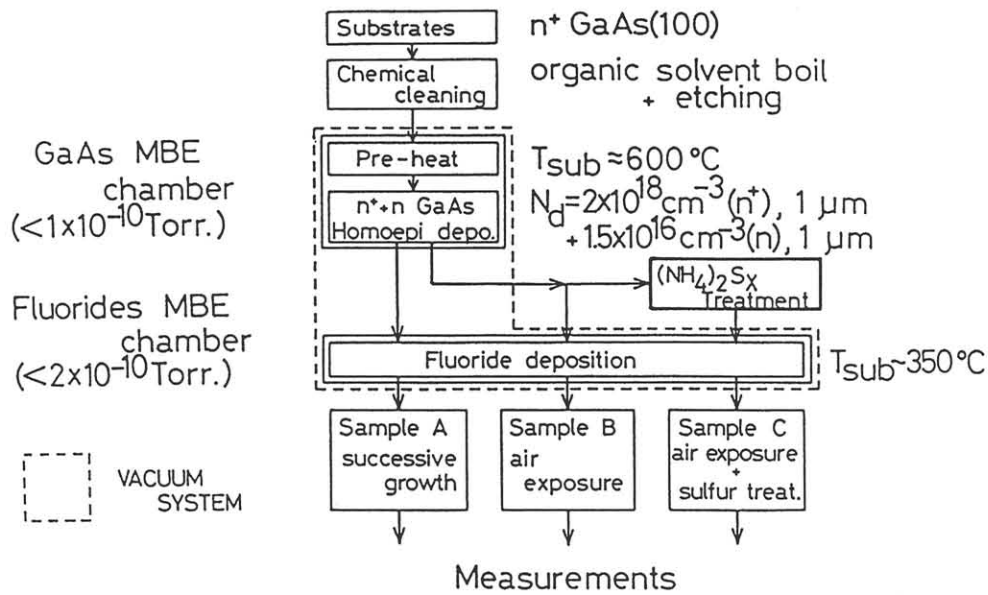


Fig. 1 Fabrication process

without breaking the vacuum or when the film is deposited on a sulfur treated surface.

2. Experimental procedure

The fluoride film is grown in an MBE (Molecular Beam Epitaxy) system, composed of two growth chambers connected by a gate value. One chamber is used for the growth of GaAs and the other is for the fluoride. In the experiments, heavily Si-doped n type wafers were chemically cleaned and etched in a $3H_2SO_4/H_2O_2/H_2O$ solution. After thermal cleaning around 600℃ in As atmospher n^+ buffer ($2x10^{18}cm^{-3}$, $1\mu m$) and active ($1\text{-}5x10^{16}cm^{-3}$, $1\mu m$) layers were grown on the n type wafers at 600℃ with a typical growth rate of $1\mu m/h$.

Then GaF_3 films 50 to 250 nm thick were deposited on them under three different conditions. The MIM(n^+) structure was also formed on the same wafer, by partially preventing homoepitaxial growth of the n layers with a metal mask. In the fist group samples A, GaF_3 films were successively deposited onto n-GaAs layers without breaking the vacuum. In the second group samples B, the films were deposited onto air-exposed GaAs layers, and in the third group samples C, the samples were immersed in $(NH_4)_2S_x$ solution for 22 hours prior to deposition of GaF_3 films. The substrate temperature during the deposition is fixed to 350℃. These processes are summarized in Fig. 1.

3. Results and discussions

It was found from C-V measurements performed on the MIM structure that the dielectric constant and the breakdown field of the GaF_3 were 6.6 and $5x10^5$ V/cm, respectively. Moreover, from I-V measurements , the plot of lnJ vs. $\sqrt{E}$ yields a straight line as shown in Fig. 2, where J and E are respectively the current density and the field. This shows that the current in the insulator is dominated by the Poole-Frenkel emission. At $5x10^5$ V/cm, the resistivity at room temperature has been evaluated to $2x10^{13}$ ohm cm.

The room temperature C-V characteristics of the MIS diodes which were fabricated by evaporation of Al electrodes are shown in Fig. 3 and 4. We can see from Fig. 3(a) that the

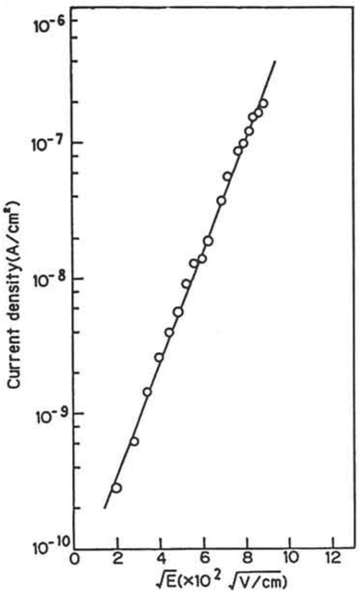


Fig. 2
I-V measurement of GaF_3/GaAs MIM diode

capacitance changes from the accumulation capacitance C_{ACC} to the deep depletion value in the dark condition or it changes from C_{ACC} to the inversion value under intense illumination by a He-Ne laser. The C_{ACC} and C_{INV} values were experimentally determined using the MIM structure and the carrier concentration of the n-layer. As shown in Fig. 3(b), the low frequency capacitance is increased towards the negative bias under illumination, which strongly suggests that an inversion layer is formed at the interface.

The C-V characteristics of the samples C(Fig. 4a-b) are similar to those of the sample A, although the capacitances under the posi-

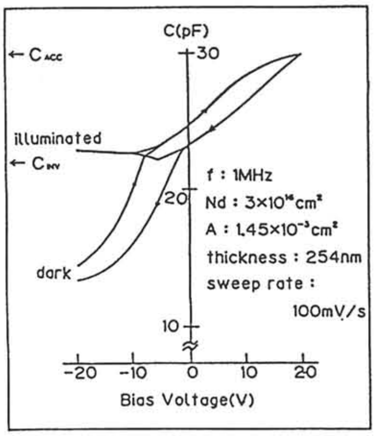
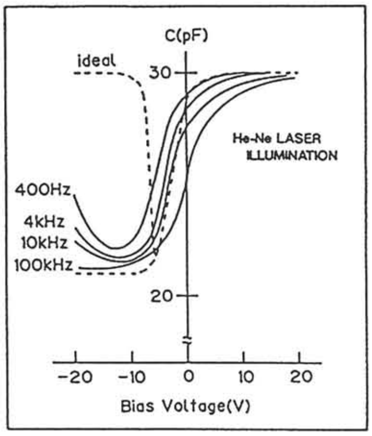


Fig. 3 Non treated sample. The fluoride is grown on the GaAs without breaking the vacuum.
a) 1MHz C-V characteristic of MIS(Al/GaF_3/GaAs) diodes



b) Frequency dependence of the C-V curve. The sample is illuminated with a He-Ne laser of 3 mW

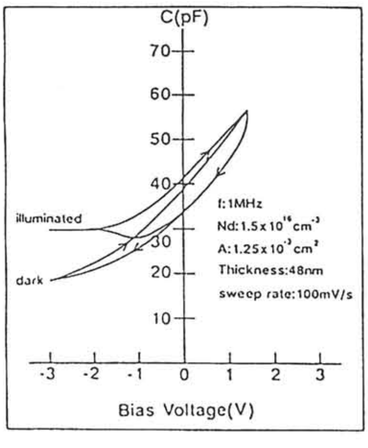
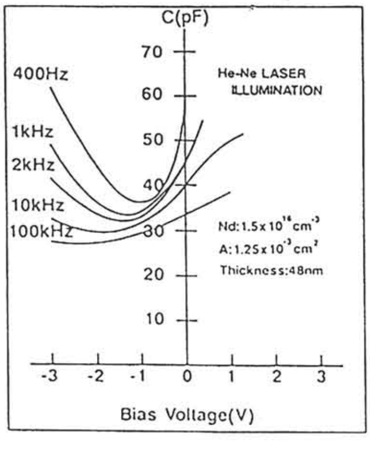


Fig. 4 $(NH_4)_2S_x$ treated sample.

a) 1MHz C-V characteristic of MIS(Al/GaF_3/GaAs) diodes



b) Frequency dependence of the C-V curve. The sample is illuminated with a He-Ne laser of 3 mW tive bias do not reach C_{ACC} because of a large leakage current. On the other hand, the C-V characteristics were much worse in the samples B. These results show that the sulfur treatment is effective to reduce the interface states which are generated by air exposure of GaAs surfaces.

For the case of successive growth of GaAs and GaF_3 layers, the interface state density could be derived from the 1MHz C-V measurement (Fig. 3a). The result shown in Fig. 5, shows a U-shaped distribution in the band gap and the minimum density is about $1x10^{12}$ $cm^{-2}eV^{-1}$ near the midgap.

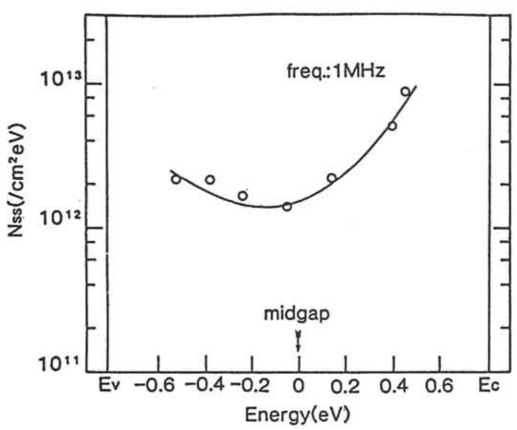


Fig. 5 Interface state density distribution in the case of sample A

4. Conclusion

Gallium fluoride has been deposited onto a homoepitaxial GaAs layer without breaking the vacuum, or on sulfur-treated GaAs surfaces. The results can be summarized as follows:

1) From MIM(n^+) structures, it was found that the dielectric constant, the breakdown field, and the resistivity of the GaF_3 films were 6.6, $5x10^5$ V/cm, and $2x10^{13}$ ohm cm, respectively.

2) From MIS structures, the interface properties of GaF_3 films were found to be good enough to generate inversion carriers under illumination.

3) The interface state density was about $1x10^{12}$ $cm^{-2}eV^{-1}$ near the midgap, for the case of successive growth of GaAs and GaF_3 layers.

4) The electronic properties are quite similar for both structures obtained without breaking the vacuum and deposited on the sulfur treated surface.

5) The sulfur treatment is effective to reduce the interface states, generated by air exposure of GaAs surfaces.

We conclude from these results that fairly good GaF_3/GaAs interfaces were obtained by successive deposition of GaF_3 on GaAs, or by deposition on sulfur-treated GaAs. The latter process will give more freedom in fabrication of GaAs MIS devices.

Acknowledgements

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References

[1] T. Waho et al, Solid State Electron. Suppl. 33 (1990) 253

[2] K. H. Kim et al, Jpn J. Appl. Phys. 27 (1988) L2180

[3] J. Fan et al, Jpn J. Appl. Phys. 27(1988) L1331

[4] A. S. Barriere et al, Appl. Surf. Sci. 41/42 (1989)

[5] Handbook of chemistry and physics 70th ed. CRC press (1989-1990)