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Surface Passivation of $In_{0.52}Al_{0.48}As$ Using $(NH_4)_2S_x$ and $P_2S_5/(NH_4)_2S$

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The $(NH_4)_2S_x$ and $P_2S_5/(NH_4)_2S$ treatments have been performed on the $In_{0.52}Al_{0.48}As$ surfaces. From XPS measurement, the residual sulfur atom on the surface has been shown to have In-S, Al-S, and As-S bonds. The improved Schottky diode performance has been achieved by the $(NH_4)_2S_x$ and $P_2S_5/(NH_4)_2S$ treatments in terms of the reverse leakage current. In addition , the advantage of $P_2S_5/(NH_4)_2S$ treatment rather than $(NH_4)_2S_x$ treatment has been shown.

I. INTRODUCTION

$In_{0.52}Al_{0.48}As$ is a promising material for quantum well structures lattice matched to InP, such as high electron mobility transistors (HEMTs) and heterojunction bipolar transistors (HBTs). In spite of the great interest in these devices, it has various problems such as low Schottky barrier height and excessive leakage current in making Schottky contacts. To improve these problems, recently, a few studies of InAlAs Schottky contacts have been reported.[1),2)]

On the other hand, a number of studies have been reported to improve the electronic properties of III-V compounds by sulfur treatments over the past few years.[3)] Solutions used in these studies are Na_2S, $(NH_4)_2S_x$, and $P_2S_5/(NH_4)_2S$. Treatment in these solutions removes surface oxides and protects the surface from oxidation by forming an overlayer of sulfur. Various effects, such as enhancement in PL intensity[4)], dependence of Schottky barrier height on the work function of the contact metal[5)], and improvements in C-V characteristics[6)] have been observed.

In this work, we have investigated the chemical passivation mechanisms of the InAlAs surface by both $(NH_4)_2S_x$ and $P_2S_5/(NH_4)_2S$ treatments, and the results were compared with the respective solutions.

II. EXPERIMENTAL

The samples were S-doped n-type InAlAs epitaxial layer($n=5x10^{16}cm^{-3}$) lattice-matched to InP(100) substrate. They were etched in $H_3PO_4:H_2O_2:H_2O$ solution for 5 sec to remove the native oxide, and thoroughly rinsed in DI water. Then the samples were immediately dipped into a solution of $(NH_4)_2S_x$ at 50 ℃ for 30 sec or $P_2S_5/(NH_4)_2$ [0.9g P_2S_5 is dissolved in 30 ml of aqueous $(NH_4)_2S$ solution.] at R.T. for 30 sec and were rinsed in DI water very briefly. After they were blown dry with N_2 gas, the surface residual films were sublimated in vacuum with $2x10^{-6}$ Torr for 30min.

The evaluation of surface properties was performed by Auger electron spectroscopy (AES), X-ray photoelectron spectroscopy (XPS), and Secondary ion mass spectrometry (SIMS). XPS measurements were performed in order to investigate the chemical bonding of the sulfur.

In order to study the effect of both $(NH_4)_2S_x$ and $P_2S_5/(NH_4)_2$ treatments, the I-V characteristics of Au/InAlAs Schottky diodes were measured.

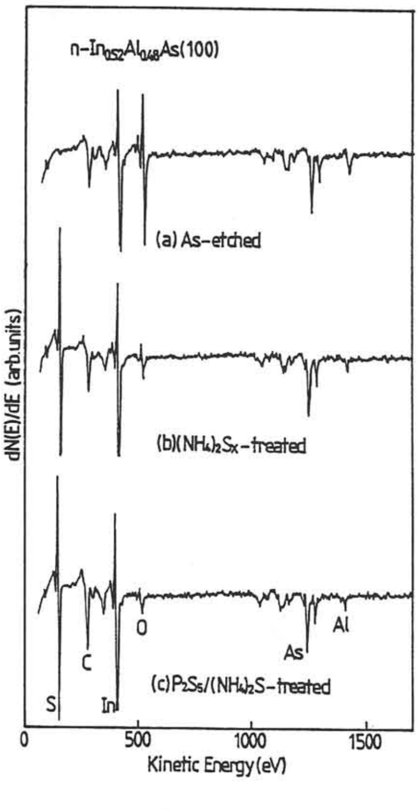
III.RESULTS AND DISCUSSION

Figure 1 shows the AES spectra, dN(E)/dE, from InAlAs surfaces. The samples were prepared by the following processes: (a)chemical etching, i.e., untreated with sulfur solution, (b)$(NH_4)_2S_x$-treated and (c)$P_2S_5/(NH_4)_2S$-treated. As shown in Fig.1(a), the presence of carbon and oxygen is revealed by the signals at 272 eV and 510 eV, respectively. Thus, the as-etched surface is covered with a surface contamination and a native oxide, and they cannot be removed perfectly by chemical etching.

The oxygen signal is, however, reduced and the sulfur signal appears at 152 eV after the $(NH_4)_2S_x$-treatment shown in Fig.1(b). Furthermore, by the $P_2S_5/(NH_4)_2S$ treatment, more improvement is observed in both oxygen reduction and sulfur increase.

Figure 2 shows XPS narrow spectra of the In 3d5/2, Al 2p, and As 3d on the InAlAs surface after (a)chemical etching, (b)$(NH_4)_2S_x$-treatment and (c)$P_2S_5/(NH_4)_2S$-treatment. For the as-etched surface, two peaks are observed in the As 3d spectra. The larger peak at 41.0eV results from the In-As or Al-As, and the small peak at 44.9eV indicates As-O bonding. After the $(NH_4)_2S_x$ or $P_2S_5/(NH_4)_2S$ treatment [Fig.2(b),(c)] the 44.9eV peak vanishes and the 41.0eV peak becomes narrow. In addition, broad In and Al peaks in Fig.2(a) become narrow and are slightly shifted after the sulfur treatments in Fig.2(b),(c).

Fig. 1
AES spectra from InAlAs surface:
(a) as-etched,
(b) $(NH_4)_2S_x$ and
(c) $P_2S_5/(NH_4)_2S$



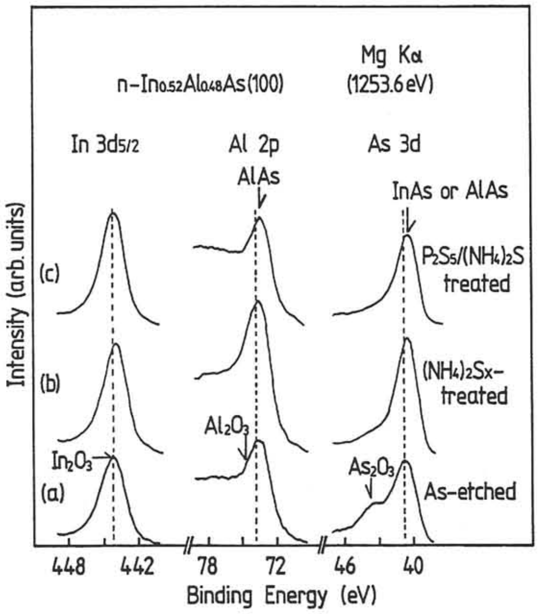


Fig. 2 XPS spectra from InAlAs surface: (a)as-etched, (b)$(NH_4)_2S_x$, and (c)$P_2S_5/(NH_4)_2$

From the above results, surface In, Al and As oxides are removed by both $(NH_4)_2S_x$ and $P_2S_5/(NH_4)_2S$ treatments. Furthermore, In-S, Al-S, and As-S bondings are confirmed by the grazing XPS analysis.

Figure 3 shows changes of the coverage ratio of sulfur against heating temperature. The coverage ratio of sulfur is normalized by the Auger peak-to-peak height (APPH) of sulfur (152eV) obtained at 200 ℃. In both treatments, the coverage ratios of sulfur atoms are constant up to 300 ℃. The sulfur coverage of $P_2S_5/(NH_4)_2S$ treatment is more resistant to

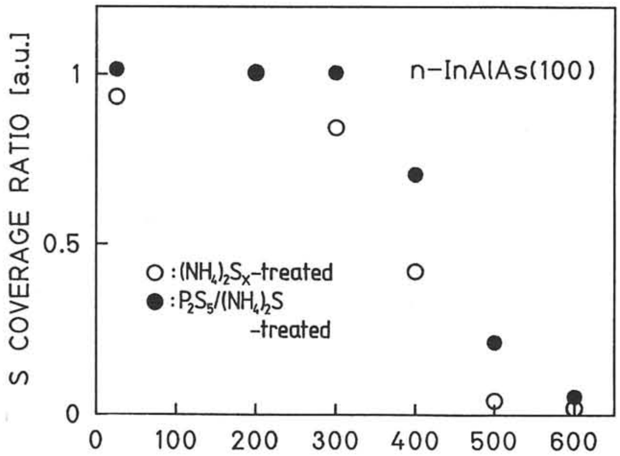


Fig. 3 Coverage ratio of sulfur against heating temperature

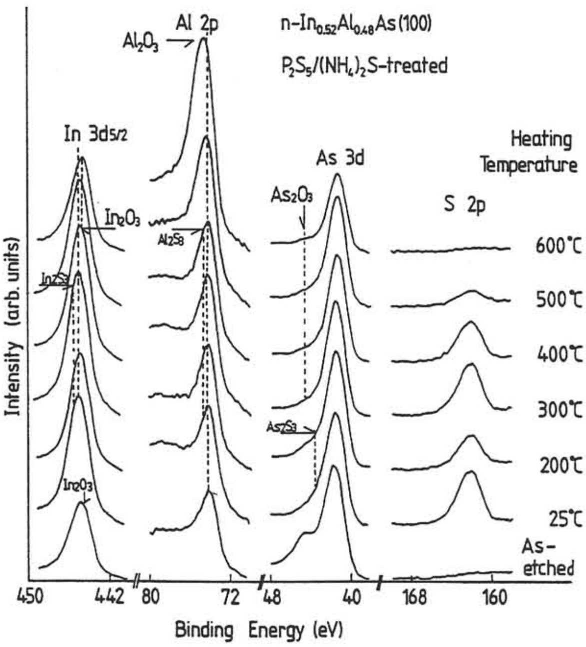


Fig. 4 The changes of XPS spectra from InAlAs surface after $P_2S_5/(NH_4)_2S$ treatment with increase in temperature.

high temperature as compared with $(NH_4)_2S_X$. These results indicate that the $P_2S_5/(NH_4)_2S$ treatment is more promising than $(NH_4)_2S_X$ treatment.

Figure 4 shows changes of XPS narrow spectra of the In 3d5/2, Al 2p, and As 3d on the InAlAs surface after $P_2S_5/(NH_4)_2S$ treatment. When samples were heated below 300 ℃, S-In, S-Al and S-As bonds are observed. But, at higher temperature heating above 300 ℃, S-As bond gradually disappears and O-As bond appears. Moreover above 400 ℃, S-In bond vanishes and O-In bond observes. S-Al bonds are stable up to 500 ℃, but above 500 ℃, S-Al bond gradually disappears. This indicates that Al-S bond is thermodynamically stable. These results suggest that the sulfur treatments play an important role in protecting InAlAs surface from oxidation.

Figure 5 shows the forward and reverse I-V characteristics for Au/$In_{0.52}Al_{0.48}As$ Schottky diodes: (a)as-etched, (b)$(NH_4)_2S_X$ and (c)$P_2S_5/(NH_4)_2S$. As-etched Schottky diode has low barrier height and high reverse leakage current. The $(NH_4)_2S_X$ treated diode, however, shows much improved I-V characteristics. In particular, the $P_2S_5/(NH_4)_2S$ treated diode has much lower reverse current density and larger Schottky barrier height than the $(NH_4)_2S_X$ treated diode.

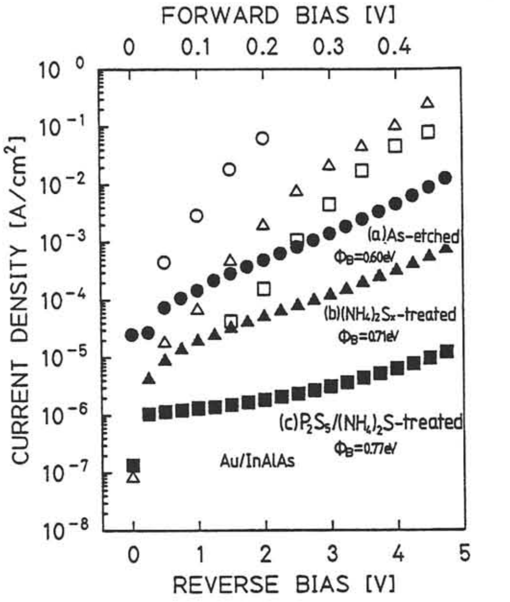


Fig. 5 Forward and reverse I-V characteristics for Au/InAlAs Schottky diodes

IV.SUMMARY

In summary, we have shown that the low leakage current on Au/$In_{0.52}Al_{0.48}As$ Schottky diodes can be attained by the $(NH_4)_2S_X$ and $P_2S_5/(NH_4)_2S$ treatments. The decrease of leakage current is attributed to the oxygen reduction and sulfur coverage of the surface. The $P_2S_5/(NH_4)_2S$ treated surface is more profitable to Schottky properties than $(NH_4)_2S_X$ treated surface.

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