Ag/Al Schottky Contacts on n-InP

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Schottky contacts have been fabricated on n-InP using a Ag/Al/InP configuration where the Ag and Al thicknesses are 1000 and 40–50Å, respectively. Diodes fabricated on InP substrates with n = 7 × 10^16 cm^-3, have effective barrier heights, \( \Phi_{\text{eff}} \), of 0.4 eV and reverse bias leakage current densities of >4 A/cm² at \( V_r = -3V \). Appropriate heat treating at temperatures between 400–500 °C raises barrier heights by as much as 0.25 eV, resulting in \( \Phi_{\text{eff}} \approx 0.65 \) eV and reverse bias leakage current densities less than 0.002 A/cm². Diode characteristics are found to vary dramatically with different surface preparations prior to metallization; results of x-ray photoelectron spectroscopy (XPS) and Auger electron spectroscopy (AES) depth profiling studies indicate that native oxides which are predominantly InPO₄ produce superior contacts and that aluminum first reacts with the native oxide and then migrates through the silver to the free metal surface which results in the dramatic improvements observed upon annealing.

Key words: InP, Schottky contacts, metallization.

1. INTRODUCTION

The formation of a high quality Schottky contact on InP is an essential prerequisite for the development of InP for use in microwave devices, high speed transistors and charge control devices. In particular, if InP/GaInAs heterostructures are to be used in the fabrication of ultra-high speed two-dimensional electron gas devices all electrical contacts will be made to an n-InP epitaxial layer that is doped in the range 10^15–10^18 cm^-3. It is, therefore, imperative that a high quality Schottky contact on n-type InP be realized. The formation of conventional Schottky contacts using single component metallizations have, however, yielded consistently low barrier heights and correspondingly high reverse bias leakage currents when applied to n-InP.

It has been found that the barrier height for metal/n-InP has consistently been in the range of 0.40 to 0.55 eV due to Fermi level pinning for metals deposited on either vacuum cleaved or chemically cleaned surfaces. In an attempt to increase the barrier height, some groups have used the approach of the intentional insertion of an interfacial insulator, beyond the native oxide present on InP after chemical cleaning. This paper reports the formation of Schottky contacts, without an intentionally grown interfacial oxide, that have increased barrier heights and reduced leakage currents using a Ag/Al layered metallization on n-InP. This metallization technique takes advantage of the native oxide present on the InP after chemical cleaning and incorporates an annealing step to realize device quality Schottky contacts.

2. EXPERIMENTAL PROCEDURE

Diode fabrication began with (100) oriented InP substrates (n = 7 × 10^16 cm^-3). Ohmic contacts were formed on the backside of the substrate by evaporating Au-Ge/Ni and annealing at 480 °C for 90 sec in flowing N₂. The samples were then degreased with sequential rinses in TCE, acetone and methanol and subsequently given one of three chemical cleaning procedures prior to the Schottky metallization. The cleaning procedures used were as follows:

1. 1 min dip in HF followed by a 5 min rinse in D.I. water and a N₂ blow-dry
2. 2 min dip in KOH:methanol (2.5g:200 ml) followed by sequential rinses in methanol and isopropyl alcohol and a N₂ blow-dry
3. 2 min dip in KOH:methanol (2.5g:200 ml) followed by sequential rinses in methanol and isopropyl alcohol the sample is then given a 10 min rinse in D.I. water followed by a N₂ blow-dry; the sample is subsequently dehydrated by heating at 140 °C for 15 min at a pressure of \( \approx 10^{-2} \) Torr

The samples were then loaded into the evaporator chamber where \( \approx 40–50 \) Å of Al followed by 1000Å of Ag were e-beam evaporated sequentially without breaking vacuum. The base pressure in the vacuum chamber was always < 10^-6 Torr. Square diodes, 100 × 100 μm, were formed either by liftoff or by conventional patterning and etching after metallization. The finished contacts were then annealed at various temperatures for 90 sec in flowing N₂. The heat treatments consisted of placing the samples on a room temperature quartz spade and then inserting the spade into a tube furnace set at the desired temperature.

Electrical characteristics were determined with a Hewlett-Packard 4145A Parameter Analyzer. In
addition, the native oxide chemistry of the InP prior to metallization was analyzed with x-ray photoelectron spectroscopy (XPS) and the metallurgical structure of the contacts after metallization, before and after annealing, was examined by Auger electron spectroscopy (AES) depth-profiling.

3. RESULTS AND DISCUSSION

3.1 Electrical Characteristics

Current-voltage characteristics for contacts formed using cleaning procedure C are shown in Fig. 1. At −3 V reverse bias the as deposited contact had a leakage current density of ~10−6 A/cm². After annealing at 460 °C for 90 sec the leakage current was reduced by more than 3 orders of magnitude to ~10−3 A/cm². The effective barrier height, Φ_{eff}, for these diodes also increased upon annealing from 0.4 to 0.65 eV. Φ_{eff} was calculated from the following relation:

\[ \Phi_{\text{eff}} = kT/q \ln(A^*T^2/J_s) \]  

(1)

where \( J_s \) is the saturation current density and \( A^* \) is the modified Richardson constant for n-InP, taken to be 9.36 A/cm²K² for an effective mass, \( m^* = 0.078 m_0 \). These values for barrier height and leakage current compare favorably with any other technique for Schottky contact formation on n-InP doped to this level that does not involve the intentional growth of an additional insulator prior to the Schottky metal deposition. For the diodes in Fig. 1, the electron concentration was \( \times 10^{18} \text{ cm}^{-3} \) as determined from capacitance-voltage measurements.

The ideality factor, \( n \), was calculated from the forward bias characteristics using the relation:

\[ n = q/kT [\partial V/\partial(\ln J)] \]  

(2)

and was found to increase from ~1.3 to 1.7 upon annealing. This increase in \( n \) was typical for cleaning procedures B and C. Samples prepared with procedure A exhibited a similar increase to ~1.5. The high values found for ideality factors indicate that the simple thermionic emission model for current flow is not entirely accurate for Ag/Al-InP Schottky contacts. Therefore, throughout this work we refer to an effective barrier height, \( \Phi_{\text{eff}} \).

Leakage current and \( \Phi_{\text{eff}} \) calculated using Eqn. 1, as a function of annealing temperature are shown in Figs. 2a and 2b. All samples were annealed for 90 sec. As can be seen in Fig. 2a, samples treated with procedures B and C had a minimum leakage current density of ~10−3 A/cm² that was achieved at an annealing temperature, of 460 °C. Also plotted are the results for diodes that were cleaned using procedure A. These diodes exhibit a similar behavior, but have leakage current densities that are almost 2 orders of magnitude higher than the samples that were cleaned using preparations B and C. In Fig. 2b, the dependence of \( \Phi_{\text{eff}} \) on annealing temperature shows a broad maximum of 0.65 eV at approximately 460 °C for the B and C samples which, as is to be expected, corresponds to the minimum leakage current. Not surprisingly, the diodes treated with cleaning procedure A again exhibited a similar temperature dependence, but with a much smaller increase in \( \Phi_{\text{eff}} \). This is to be expected in light of the much larger leakage currents of the A samples as compared to the B and C samples.

The results cited up to this point are for square