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Ohmic contacts with palladium diffusion barrier on III–V semiconductors

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A B S T R A C T

Ohmic contacts with a palladium (Pd) diffusion barrier were formed on GaAs substrates. The metal-contact structure consists of a gold-based-alloy/Pd/semiconductor-substrate. Characteristics of the deposited Pd films by "electroless" deposition on semiconductor-substrates are reported. SIMS analysis realized on the metal-semiconductor structures demonstrates the capability of the Pd films to act as a diffusion barrier. Contact resistance of the ohmic contacts was measured by the transmission line method (TLM).

1. Introduction

The III-V semiconductor technology is now a mature technology. III–V semiconductor devices find application in different technological areas. However, modern devices based on quantum well or super-lattice structures even require intensive research to develop suitable ohmic contacts. Ohmic contacts on modern devices must comprise very shallow regions of extension limited to few hundreds of nanometers. Good ohmic contacts must have contact resistance values of less than 10^{-5} Ω cm^2 [1]. The formation of shallow ohmic contacts presents several difficulties because of the huge quantity of physicochemical phenomena that happen at the metal–alloy interface [1]. Therefore, ohmic contacts on modern devices must include diffusion barriers in order to confine the contact extension.

In this study we will use GaAs substrates because of their wide use in III–V semiconductor technology. The main factors affecting the contact resistance of ohmic contacts are:

i) The physicochemical properties of the semiconductor (doping level and work function) and the surface characteristics (surface state density).
ii) The metal or metal-alloy selected to form the ohmic contact.
iii) The distinct processes applied to the semiconductor surface before the formation of the ohmic contact (it must include all the necessary stages to prepare the surface, such as the chemical-mechanical etching or the surface passivation processes).
iv) And the thermal annealing processes required to guarantee the electrical and mechanical stability of ohmic contacts.

There are various methods used for the fabrication of ohmic contacts. However, as a general rule a thermal annealing step is used for achieving contact integrity, therefore it is necessary to include this stage in any process to develop good ohmic contacts. The typical methods for ohmic contact formation on III-V semiconductor compounds can be summarized as follows:

A) The use of an interfacial degenerated thin film of the same semiconductor at the metal–semiconductor interface. The extension of the ohmic contact depends on the diffusion coefficient of the dopant and the chemical stability of the compounds formed at the interface.
B) Inclusion of an interfacial semiconductor–semiconductor heterojunction [2], with the lower-band gap semiconductor in contact with the metal. Typical examples are the GaAs ohmic contacts formed with an intermediate indium film. The annealing processes could produce films of InAs or $Ga_{1-x}In_xAs$ in close contact with the final gold metal-alloy. As the barrier produced at the lower-band gap semiconductor is minor, the contact resistance is greatly reduced.
C) Several kinds of ohmic contacts with diffusion barriers are reported in the literature. Some of these contacts are based on refractory metals such as tungsten, titanium or some noble metal based alloys, such as Pd–Ag and Pd–Au. Diffusion barriers with palladium (Pd) use films of ~10 nm thickness [1], however the reported results are incomplete to define the barrier functionality of the Pd films.

The preceding description refers to the general process for the ohmic contact formation. The entire process includes some wet steps applied at the semiconductor surface that unavoidably produce several metallic oxides, due to the use of water-based solutions or some other organic solvents. Therefore, it is necessary

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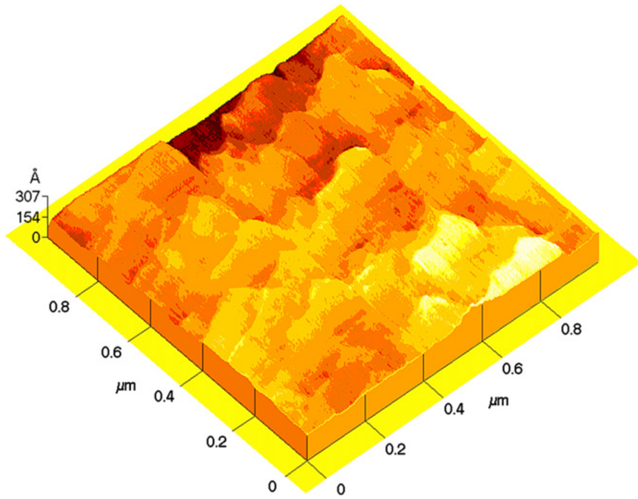

Fig. 1. GaAs substrate with a Pd film deposited during 40 s. The resulting surface presents a roughness (*rms*) smaller than 10 nm.

to consider the inclusion of a stage to reduce the oxide films formed at the semiconductor surface [2]. This stage can be reached through a Pd thin film at the semiconductor surface.

Considering the high hydrogen solubility in Pd, the native oxides at the semiconductor surface can be reduced by including an additional annealing stage during the formation of the ohmic contacts in the hydrogen atmosphere.

In this work a process for the formation of ohmic contacts with a Pd diffusion barrier is reported. The ohmic contacts were realized on GaAs substrates. The complete ohmic contact consists of a gold–alloy–palladium–semiconductor structure [3]. In order to simplify the metallization process, the Pd film was deposited by the electroless process and the gold-based alloy by vacuum thermal evaporation. The procedure for the ohmic contact formation comprises two steps: In the first step the Pd film is deposited onto the semiconductor surface and the structure is annealed under pure hydrogen atmosphere to reduce the possible semiconductor oxides. In the second stage, depositing a gold-based alloy by vacuum evaporation over the Pd film completes the metallization scheme. As a part of the second stage an annealing process at 300 °C is applied to the structure under inert atmosphere conditions to reach contact integrity.

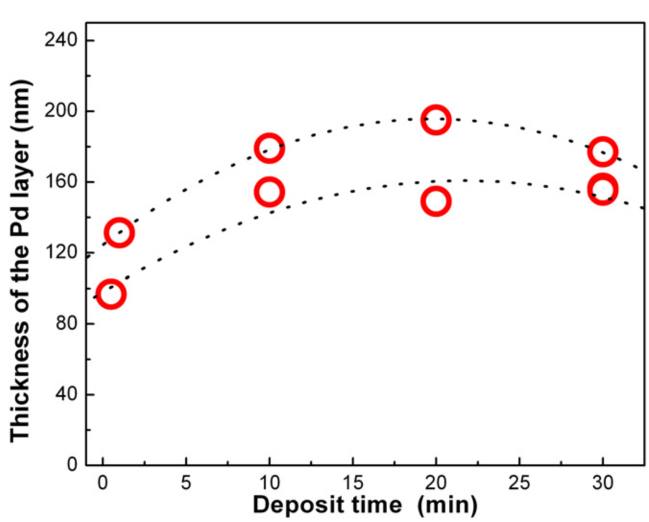

Fig. 2. Growth rate of Pd films on GaAs substrates deposited by the electroless method.

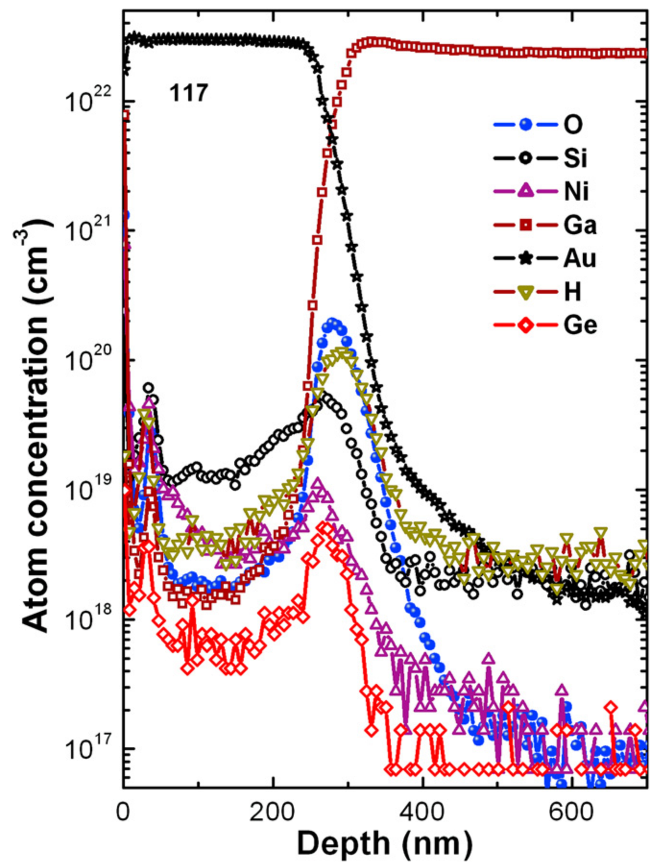

Fig. 3. Chemical composition analyses by SIMS in the Au:Ge:Ni/GaAs:Si structure. The sample was annealed at 300 °C in N_2 atmosphere.

2. Experimental details

Before the formation of ohmic contacts, the surface of the substrates was cleaned carefully. A standard cleaning procedure for cleaning GaAs was used [4–8], which is used to remove organic residues and films from GaAs wafers. In the process, it oxidizes the GaAs and leaves a thin oxide on the surface of the wafer which should be removed, a pure GaAs surface is desired. The Pd films were deposited on GaAs substrates by the electroless method, using a variant of the reported one in [9]. The chemical bath is a mixture of deionized water (100 ml), 0.01 ml of HF (12 M) and 10 mg of $PdCl_2$. Pd films were deposited by immersing the substrates for a period of 10–120 s.

The samples surface was analyzed with an atomic force microscope (AFM) of Park Scientific Instruments; CP0175 model. Thickness and refractive index of the Pd films were measured by ellipsometry, using a Gaërtner ellipsometer; model L117. Pd films used to form the ohmic contacts were deposited for a duration of 120 s, for a thickness of 120 nm and a surface roughness (*rms*) under 1 nm. The structure was annealed in a pure hydrogen atmosphere at 300 °C to reduce the possible oxides at the uncovered sites of the semiconductor surface.

To complete the ohmic contacts, on the Pd-semiconductor a gold-based alloy was deposited by vacuum evaporation with an Edwards 6306 equipment; at a vacuum of 3.0×10^{-6} mbar. For *n*-type substrates the alloy was Au–Ge–Ni (166 mg/24 mg/10 mg), and for *p*-type substrates the alloy was Au–Zn (166 mg/34 mg) [10]; the film thickness of the gold-based alloy was 350 nm. The final step in the formation of the ohmic contacts, it is annealing of the complete structures at 300 °C in a pure N_2 atmosphere by 30 min.