Chapter 1

Introduction

1.1 Research Background of Copper Metallization for GaAs-based Devices

In the past decades, GaAs ICs are generally used for military purposes, such as satellite, radar and etc. With the rapid development of the high-frequency communication industry, GaAs integrated circuits become very important for wireless commonication applications. Ever since IBM first engaged in copper interconnection technology,[1-3] copper metallization has drawn considerable attention in the silicon IC industry. Conventionally, gold is used as a contact and interconnect metal for GaAs-based microwave devices and circuits. GaAs devices such as metal semiconductor field-effect transistors (MESFET's), high electron mobility transistors (HEMTs), and heterojunction bipolar transistors (HBTs) usually use Ti as adhesion layer, and Au as the metallization metal for interconnect metals, transmission lines, inductors and ground plane metallization.. In GaAs-based and InP-based HEMT metallization process, gold is extensively used for the device fabrication, such as Schottky contacts (Ti/Pt/Au), Ohmic contacts (AuGe/Ni/Au) and airbridge interconnect (Ti/Au) due to its high electrical conductivity and relative chemical inertness. On the other hand, the fabrication of the GaAs based HBTs usually use the n-type AuGe/Ni/Au and p-type Ti/Pt/Au or Pt/Ti/Pt/Au ohmic contacts. Meanwhile, HBTs are usually passivated with silicon-nitride films by plasma-enhanced chemical-vapor-deposited (PECVD), if Cu is in direct contact with the silicon nitride film of poor quality, copper atoms may diffuse through the defects of the silicon nitride film during the heat treatment of the metallization process and the leakage current will increase owing to copper diffusion.[4] Using copper in place of gold as a metallization metal for the GaAs-based devices has the advantages of low resistivity, high thermal conductivity and low cost. Copper diffuses very fast into silicon if no diffusion barrier is used. It is generally confirmed that the rapid diffusion results from singly ionized interstitial copper which migrates as a positively charge ion in silicon.[5] Similarly, copper is known to diffuse rapidly into GaAs via a kick-out mechanism if no diffusion barrier [6] is used, and creates deep traps that degrade device characteristics. Although copper metallization has played an important role in the silicon IC industry, reports on the copper metallization for GaAs devices are relatively few.[7-9]

In recent years, the thermal stability of Ta/GaAs for Schottky gate use was reported with the experimental results[10-16] and theoretical calculations of thermodynamics.[17-19] Moreover, the electrical properties of the Cu/Ti/GaAs structure for Schottky gate use[20] or Cu/GaAs for ohmic contact use[21] have also been reported. More recently, considerable efforts have been devoted to the realization of the barrier effect of Ta between Cu and GaAs after annealing at temperatures of up to 500 °C.[22] It also reported that the MESFET's metallized using Cu/Ta layers exhibited good power performance and thermal conductance and demonstrated excellent thermal stability after thermal stress.[23-24] In addition, alloyed PdGe, non-alloyed Pt/Ti/Pt/Cu, and alloyed PdGe gold-free ohmic metal systems were also used for the HBTs applications.[25] In this thesis, we extend the work to use a new Cu/Mo/Ge/Pd ohmic contact to fabricate InGaP/GaAs heterojunction bipolar transistors and characterize the microstructural evolution of Cu/Ta/GaAs with thermal annealing.

1.2 Overview of the Thesis

This dissertation is devoted to the study of the copper metallization for InGaP/GaAs heterojunction bipolar transistor applications and mechanism of the microstructural evolution for the Cu/Ta/GaAs structure after thermal annealing. Overall, the thesis is divided into 5 chapters, including:

In chapter 2, before going through the main subjects, an order-disorder InGaP/GaAs heterostructure grown by metal-organic chemical vapor deposition (MOCVD) is introduced. We describe the optimization of the epitaxial growth using alkyls and hydrides as starting materials for GaAs and ordering InGaP heterostructures. Energy band gap of ordering InGaP can be achieved to 1.84 (eV) by photoluminescence (PL) analysis after 650°C growth condition. On the other hand, energy band gap of disordering InGaP can be achieved to 1.93 (eV). Raman scattering spectra also used to identify the lattice-matched InGaP/GaAs heterostructure. The degree of structural order was usually judged by the band gap, on the other hand, Raman spectra was very sensitive to microstructural information. Therefore, it can be used to further characterize the ordering of InGaP/GaAs heterostructure in detail.

In chapter 3, the feasibility of using novel Cu/Mo/Ge/Pd ohmic contacts on n^+-GaAs for InGaP/GaAs heterojunction bipolar transistors (HBTs) is investigated. The electrical and material characteristics of the Cu/Mo/Ge/Pd/n^+-GaAs structure were also studied. After thermal annealing at 350℃, the specific contact resistances of the copper-based ohmic contacts Cu/Mo/Ge/Pd was measured to be $10^{-7}\ \Omega\ \mathrm{cm}^2$ range. Judging from the data of sheet resistance, X-ray diffraction analysis, Auger electron spectroscopy, and transmission electron microscopy, the Cu/Mo/Ge/Pd contact structure was very stable after annealing at 350℃. However, after 400℃ annealing, the reaction of copper with the underneath layers started to occur and formed MoGe$_2$, Cu$_3$Ga and Ge$_3$Cu phases. An InGaP/GaAs HBT with Cu/Mo/Ge/Pd contact metals was fabricated and compared with an HBT fabricated with traditional Au/Ni/Ge/Au contact metals. These two kinds of HBTs showed similar device characteristics. After performing a high current-accelerated stress test at a current density of 120 kA/cm^2 for 24 h, the device with the Cu/Mo/Ge/Pd ohmic contacts still exhibits excellent electrical characteristics.

In chapter 4, the diffusion behavior and microstructure evolution of Cu/Ta/GaAs multilayers after thermal annealing were investigated and the mechanism was proposed. From the results of sheet resistance measurement, X-ray diffraction analysis, Auger electron spectroscopy and transmission electron microscopy, the Cu/Ta film on GaAs was found to be very stable up to 500 °C annealing without Cu migration into GaAs. However, after annealing at 550 °C, the interfacial mixing of Ta with GaAs substrate occurred, resulting in the formation of TaAs$_2$, and the diffusion of Ga through the Ta layer formed the Cu$_3$Ga phase at the Cu/Ta interface. After annealing at 600 °C, GaAs reacted with Ta and Cu and formed TaAs and Cu$_3$Ga phases owing to the Ga migration and interfacial instability.

In chapter 5, important conclusions are drawn, including (1) The abruptness and ordering of InGaP/GaAs heterostructure was achieved as judged by DCXRD, SEM, Raman scattering spectra and PL. (2) Novel Cu/Mo/Ge/Pd ohmic contact on n$^+$-GaAs for InGaP/GaAs heterojunction bipolar transistors (HBTs) was investigated and demonstrated to have good thermal stability. (3) The diffusion mechanism of Cu/Ta/GaAs multilayers after thermal annealing are proposed based on the TEM, Auger and X-ray analysis data. .

1.3 References

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