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Physica B 368 (2005) 58–63
PHYSICA B
www.elsevier.com/locate/physb

The effect of native oxide layer on some electronic parameters of Au/n-Si/Au–Sb Schottky barrier diodes

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Received 15 June 2005; received in revised form 26 June 2005; accepted 28 June 2005

Abstract

We have fabricated Au/n-Si Schottky barrier diodes (SBDs) with and without thin native oxide layer to explain whether or not the native oxide layer is effective on some electronic parameters such as ideality factor, barrier height (BH), series resistance, interface state density and rectifying ratio. The native oxide layer on Si surface cleaned using RCA cleaning procedure was obtained by exposing the Si surface to clean room air for 10 h, before metal evaporation. We calculated electronic parameters of these two diodes and compared them. The values of 1.04 and 0.742 eV for ideality factor and BH of the reference sample, respectively, and the values of 1.15 and 0.743 eV for the ideality factor and BH of Au/native oxide/n-Si, respectively, were obtained. The values of all electronic parameters of Au/native oxide/n-Si metal–insulator–semiconductor (MIS) SBDs except for the rectifying ratio have been found to be higher than values of the reference sample (MS).

PACS: 73.20.−r; 73.30.+y; 73.40.Sx

Keywords: Schottky barrier; Series resistance; Interfacial layer; Interface state density; Ohmic contact; Silicon

1. Introduction

Metal–semiconductor (MS) interfaces are an essential part of virtually all semiconductor electronic and optoelectronic devices. One of the most interesting properties of MS interfaces is its Schottky barrier height (SBH). The existence of an insulating oxide layer at the MS interface converts the devices into a metal–insulator–semiconductor (MIS) diode [1–6]. Therefore, the interfacial parameters such as the interface states and interfacial layer cause strong masking of the electrical characteristics of the Schottky barrier diodes (SBDs) [7–11].

The first studies on the interface layer in Schottky diodes were carried out by Cowley and

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0921-4526/$ - see front matter
doi:10.1016/j.physb.2005.06.036

Sze [1], who obtained their predictions from an analysis of BHs with different metallization as a function of the metal work function. Tseng and Wu [2] investigated the effect of the presence of an interface layer and interface states on the behavior of Schottky contacts, discussed the occupation of the interface states as a function of applied voltage and extracted the density distribution of the interface states in the semiconductor band gap from the non-ideal I–V characteristics. Card and Rhoderick [3] examined the effect of the interface layer on the ideality factor of the forward bias I–V characteristics. Horvath [4] showed that from the forward and reverse I–V characteristics, the interface state energy distribution and relative thickness of the interfacial layer may be evaluated. Aydın et al. [5] calculated the interface state density distribution from the nonideal forward bias I–V characteristics of the SBDs with and without taking into account the series resistance. Moreover, Cattopadhyay [12] and Pandey and Kal [13] extracted the expressions to calculate the energy distribution of the interface states.

The existence of native oxide film on silicon surfaces degrades the control ability of the quality of device fabrication processing, the performance and reliability of semiconductor devices themselves. Therefore, to form the native oxide film on the n-type silicon surface, we have fabricated the Au/n-Si Schottky diodes using the chemically cleaned n-type Si surface that is exposed to clean room air before metal evaporation. Our aim is to compare the values of ideality factor, BH, rectifying ratio, series resistance and interface state density of the sample exposed to clean room air with the reference sample and to see whether or not the performance and reliability of the devices degrade due to exposure of the Si surface to the clean room air. We have used Au as Schottky contact because it shows the rectifying behavior on n-type Si. The previously polished n-Si wafer was cleaned using the RCA cleaning procedure.

2. Experimental procedure

The samples have been prepared using cleaned and polished n-type Si wafer (as received from the manufacturer) with [1 1 1] orientation and 2–20 Ω cm resistivity. Before making contacts, the wafer was chemically cleaned using the RCA cleaning procedure (i.e., a 10 min boil in $NH_3 + H_2O_2 + 6H_2O$ followed by a 10 min boil in $HCl + H_2O_2 + 6H_2O$), with the final dip in diluted HF for 30 s, and then rinsed in DI water with ultrasonic vibration and dried by high-purity nitrogen. Au–Sb for ohmic contacts was evaporated on the back of the wafer in a vacuum-coating unit of 10^{-5} Torr. Then low-resistance ohmic contacts were formed by thermal annealing at 420 °C for 5 min in flowing N_2 in a quartz tube furnace. Then the wafer was cut into two pieces of 5 mm × 5 mm each. One of them was immediately inserted into the evaporation chamber for forming the reference Schottky contacts. This sample has been called as D1 (the reference sample). However, it has been reported that even diodes prepared by cleaving under a stream of metal in high vacuum have a very thin effective native oxide layer [8,14–18]. The other sample was exposed to clean room air for 10 h and then this sample was immediately inserted into the evaporation chamber to form Schottky contacts. This sample has been called as D2. The Schottky contacts were formed by evaporation of Au as a dot with a diameter of about 1 mm onto the sample surface. Thus, Au/n-Si samples with and without the interfacial layer were obtained. All evaporation processes were carried out in a vacuum-coating unit at about 10^{-5} Torr.

In order to observe the exposure effect of clean room air, the I–V characteristics have been measured using a HP 4140B picoamperemeter at room temperature and in the dark.

3. Results and discussion

When SBDs with a thin interfacial layer MIS are considered, it is assumed that the forward bias current at the device is due to thermionic emission current and it can be expressed as [3,8]

$$I = I_0 \exp\left(\frac{qV}{nkT}\right)\left[1 - \exp\left(-\frac{qV}{kT}\right)\right], \qquad (1)$$