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Fabrication and electrical characterization of nickel/p-Si Schottky diode at low temperature

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ABSTRACT

In this study the current–voltage and capacitance–voltage characteristics of metal semiconductor Ni/p-Si(100) based Schottky diode on p- type silicon measured over a wide temperature range (60–300 K) have been studied on the basis of thermionic emission diffusion mechanism and the assumption of a Gaussian distribution of barrier heights. The parameters ideality factor, barrier height and series resistance are determined from the forward bias current–voltage characteristics. The barrier height for Ni/p-Si(100) Schottky diode found to vary between 0.513 eV and 0.205 eV, and the ideality factor between 2.34 and 8.88 on decreasing temperature 300–60 K. A plot involving the use of φ_b versus 1/T data is used to gather evidence for the occurrence of a Gaussian distribution of barrier height and obtain the value of standard deviation. The observed temperature dependences of barrier height and ideality factor and non-linear activation energy plot are attributed to the Gaussian distribution of barrier heights at the metal-semiconductor contact. The barrier height of Ni/p-Si(100) Schottky diode was also measured over wide temperature from the capacitance-voltage study.

1. Introduction

Metal-semiconductor (MS) contacts have attracted increasing interest owing to their various potential technological applications [1–12]. The metal-semiconductor contact is a simple and technologically important in semiconductor devices. The performance of the Schottky diodes is dominated by the properties of the barrier formed at the contact interface. The quality of the diode is evaluated by the Schottky barrier height and ideality factor. For the case of an ideal Schottky diode, its barrier height should same and the ideality factor should remain almost close to unity over the temperature range. In a practical Schottky barrier [13–17], the current–voltage (I–V) characteristics of the metal-semiconductor contacts usually deviate from the ideal thermionic emission (TE) current model.

Huang et al. [18] studied the electrical characteristics of Ni/Si(100) solid-state reaction with yttrium (Y) addition. The electrical characteristic measurements reveal that no significant Schottky barrier height modulation with the addition of Y occurs. Kim et al. [19] studied the growth of Ni silicide nanowires by physical vapor deposition. The electrical and morphological changes of silicide formation were observed on a gradient Ni film thickness, which visualized the critical thickness is 60–80 nm to grow nanowires. Demirezen et al. [20] investigated the current-transport mechanisms of (Ni/Au)/$Al_{0.22}Ga_{0.78}N$/AlN/GaN Schottky barrier diodes (SBDs) over the wide temperature range of 80–400 K. Kiziroglou et al. [21] fabricated the electrodeposited Ni–Si contacts and the transport mechanisms through the formed Schottky barrier are studied. Highly doped Si is used to enable tunneling currents.

Kiziroglou et al. [22] fabricated the Ni–Si Schottky barrier diodes by electro-deposition using Si substrates and studied the I-V and capacitance-voltage (C-V) characteristics at low temperature. A mean value of 0.76 V and a standard deviation of 66 mV were reported for the Schottky barrier height at room temperature with a linear bias dependence. Nakatsuka et al. [23] investigated the effects of C^+ ion implantation into Si substrates on electrical properties of NiSi/Si(001) contacts. Zhu et al. [24] studied the I–V and C–V characteristics of Ni silicide/n-Si(100) contacts, were formed at various annealing temperatures from 350 to 800 °C. The experimental I–V data of the low temperature annealed diodes obey the traditional thermionic emission (TE) model quite well, and the barrier heights are deduced to be approximately 0.62 eV for Ni_2Si/Si and 0.67 eV for NiSi/Si diodes respectively. Roccaforte et al. [25] investigated the structural and electrical properties of Ni/Ti/SiC

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Schottky contacts upon thermal treatments. The physical information obtained from the study of this bilayer can be extremely important in the control of the electrical properties of Schottky barriers for advanced devices on SiC. Sahay et al. [26] have investigated the room temperature I-V and C-V characteristics of Ni/n-Si SBDs fabricated by the vacuum vapor deposition, and found a value of barrier height 0.73 eV from the forward bias I-V characteristics at 300 K. In this work, we have fabricated the Ni/p-Si Schottky diode and studied the electrical properties, temperature dependent I-V and C-V characteristics in the temperature range 60–300 K.

2. Experiment

The Ni/p-Si Schottky diode was fabricated on boron doped p-type (1 Ω-cm resistivity) silicon wafer of (100) orientation. Prior to back ohmic contact and Schottky contact deposition, the silicon wafer was properly cleaned and etched for native oxide removal from the surface. The wafer was first cleaned with organic solvents viz., trichloroethylene, acetone and methanol in succession then rinsed in demonized water of resistivity 18 MΩ-cm and then etched in a 40% HF solution for 1 min. After each cleaning step, the silicon wafer was rinsed thoroughly in demonized water of resistivity 18MΩ-cm for 1 min. After cleaning and etching steps, the silicon wafer was loaded in 12” vacuum coating unit Model 12A4D. Ohmic contact was established on the back side of the p-type silicon wafer by depositing high purity (99.999%) aluminum at a constant pressure of 3×10^{-6} mbar with a thickness of ~2000 A°. The back ohmic contact was annealed at 300 °C for 1 h in a vacuum of 1×10^{-3} mbar. The back ohmic contact was protected by picein.

The nickel film (Thickness~2000A°) was subsequently deposited by 12” vacuum coating unit Model 12A4D on the front side of p-type silicon wafer by using metal mask having holes of diameter 1 mm in a vacuum of 3×10^{-6} mbar to form a Schottky junction. Before metal deposition the silicon wafer was cleaned and etched in a 40% HF solution for 1 min to remove the native oxide layer formed on silicon wafer. The temperature dependent I-V measurements were performed by using a programmable Keithley 2400 source meter in the temperature range of 60–300 K using a Lake shore model 331 temperature controller cryogenics HC2. In addition, the whole I-V measurements were performed by using a computer through an IEEE-488 interface card. The C-V measurements were performed with Precision Impedance Analyzer (Wayne Kerr 6520A) and close cycle helium refrigerator with temperature controller.

3. Method of analysis

On the basis of thermionic emission-diffusion theory the current through a Schottky diode is given by Ref. [1,2].

$$I = I_S\left[\exp\left(\frac{q(V - IR_S)}{kT}\right) - 1\right] \tag{1}$$

with

$$I_S = A_d A^{**} T^2 \exp\left(\frac{-q\varphi_b}{kT}\right) \tag{2}$$

where I_s is reverse saturation current at zero bias, A_d is the diode area, A^{**} is the effective Richardson constant, T is the temperature in Kelvin, k is the Boltzmann constant, q is the electronic charge, φ_b is the barrier height, η is the ideality factor and R_s the diode series resistance. It is customary to make ln(I) versus V plots at various temperatures and extract from the straight-line portion the saturation current (I_s) by extrapolation to zero-bias and the ideality factor from the slope itself. Alternatively, a computer program is utilized to fit the experimental I-V data in the thermionic emission-diffusion Eq. (1) using least square fitting by iteration to find I_s , η and R_s [15]. Once I_s is known, the barrier height φ_b can easily be determined from (2) at any temperature for a given diode area A_d and Richardson constant A^{**} (3.2×10^5 Am^{-2} K^{-2} for p-type Si [27,28]).

4. Results and discussion

4.1. Forward I-V characteristics

The measured forward current-voltage (I-V) characteristics of Ni/p-Si(100) Schottky barrier diodes in the temperature range 60–300 K are shown in Fig. 1. These plots clearly depict linearity over several order of current. Further, they progressively become straight over a wide current range with decrease in temperature. The increase in the slope of the straight-line portion of the ln(I)-V curve and the gradual shift of the plot towards higher voltage side observed with decrease in temperature are in agreement with TED Eq. (1). The measured I-V data of Fig. 1 is fitted in TED current Eq. (1) to derive the apparent barrier parameters, namely, the barrier height, ideality factor and series resistance. The variation of these parameters as a function of temperature is shown in Figs. 2, 3 and 5, respectively.

Fig. 1 shows the variation of zero-bias barrier height φ_{b0} decreases with decrease of temperature steadily in the beginning but sharply at low temperatures. At temperature below 180 K there is deviation from linear rise in current at low bias and extra current exist at low bias below this temperature.

Decreased barrier height would mean that the ln(I)-V plots originates from higher current on the ordinate at any given temperature, i.e. the device exhibits higher current than the ideal case where the measured current will decrease much and the derived barrier height would remain flat. This extra current may be arising due to leakage effect. For extraction of barrier parameters the linear part at selective bias region used in the fitting process. The ideality factor η initially increases slowly with decrease in temperature but rises significantly below 100 K and attains a value of 8.88 at 60 K as shown in Fig. 3.

The barrier height can also be determined from the activation energy plot and for this Eq. (2) can be rewritten as

$$\ln\left(\frac{I_s}{T^2}\right) = \ln\left(A_d A^{**}\right) - \frac{q\varphi_b}{kT} \tag{3}$$

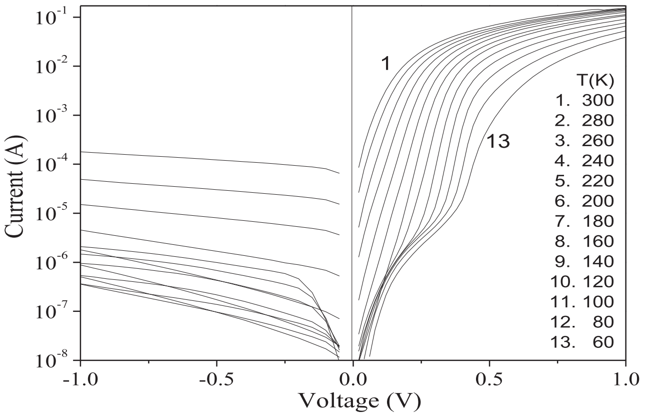

Fig. 1. The forward current-voltage characteristics of Ni/p-Si Schottky contacts measured at various temperatures.