INTERPRETATION OF TEMPERATURE DEPENDENT CHARACTERISTICS OF NON-IDEAL Al-SiO_2-pSi SCHOTTKY DIODES

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Al-SiO_2-pSi Шоттки диоды с термически выращенным окисным слоем были изготовлены для исследования доминирующего механизма транспорта тока. Характеристики *J-V* изучены в температурном диапазоне 295-370 K. Все полученные данные подтверждали, что готовые образцы имеют туннельный эффект и в транспортном механизме в температурной области 295-370 K преобладало многошаговое туннелирование, несмотря на то, что Si –«сэндвич» имеет низкую концентрацию примесей, и измерения проводились при умеренной температуре.

Al-SiO_2-pSi Schottky diodes with thermal growth oxide layer were fabricated to investigate the dominant carrier transport mechanism. *J-V* characteristics are studied in the temperature range of 295-370 K. All obtained finding confirmed that the prepared samples have tunnel effect and the current transport mechanism in the temperature region of 295-370 K was predominated by a trap-assisted multistep tunneling, although the Si wafer has low doping concentration and the measurements were made at moderate temperature.

1. INTRODUCTION

In a MIS structure a large number of carrier transport mechanism can contribute to the diode current-transport mechanism [1,2]. Until now, the literature has indicated that a complete description of the current-transport through the junction is still a challenging problem. However, the temperature dependence of *I-V* and *C-V* characteristics can give a better picture of the conduction mechanism and allows one to understand different aspects that shed light on validity of various processes involved. The predominant carrier transport mechanism can be dependent on various factors such as impurity concentration of semiconductor, process of surface preparation, formation of oxide layer, metal to semiconductor barrier height and device temperature, density of interface states and bias voltage [3]. In this study, Al-SiO_2-pSi structures were fabricated and their *J-V* and *C-V* characteristics have been measured in the different temperature to investigate the predominant carrier transport mechanisms. The effect of interfacial insulator layer and distribution of state density on I-V and C-V characteristics were analyzed. The analysis of all experimental data with low doping concentration MIS Schottky diodes indicated that the forward current transport is predominantly characterized by a multistep tunneling mechanism over moderate temperatures used in this work.

2. EXPERIMENTAL DETAILS

The Al/SiO_2/p-Si structures were fabricated on a quarter of 2 inch diameter float zone <100> p-type B (boron) doped single crystal silicon wafer having thickness of 350 μm with ~1 Ω-cm resistivity. Si wafer was decreased in organic solvent of $CHCLCCL_2$, CH_3COOH_3 and CH_3OH, etched in a sequence of H_2SO_4 and H_2O_2, 20 % HF, a solution of 6 HNO_3: 1HF:35H_2O, 20 % HF and finally quenched in de-ionized water with resistivity of 18 MΩ-cm for 3 minutes. The Al back contact was thermally evaporated by means of a tungsten filament onto the whole back side of quarter Si wafer under a pressure of ~$2x10^{-6}$ Torr in vacuum coating system. The ohmic contact was formed by sintering the evaporated Al back contact at 500 ^{o}C for 10 minutes in flowing dry nitrogen (N_2) ambient at a rate of 1.5 liter/min. This process served both to sinter the Al and to form the required thin insulator layer (SiO_2) on the upper surface of the Si wafer. After the thermal treatment Al circular dots having area of about 0.02 cm^2 and 2500 Å thick aluminum rectifying contacts were deposited at a rate of about 4 Å/s onto the SiO_2 surface of the wafer through a metal shadow mask in liquid nitrogen trapped oil-free vacuum system in the pressure of $2x10^{-6}$ Torr. The metal layer thickness and the deposition rates were monitored with the help of quartz crystal thickness monitor. The temperature dependence of current density-voltage-temperature (*J–V-T*) measurements were performed by the use of a Keithley 220 programmable constant current source together with a Keithley 614 electrometer in a Janes vpf-475 cryostat with a Lake Shore model 321 auto-tuning temperature controllers in a vacuum of $5x10^{-4}$ Torr.

3. RESULTS AND DISCUSSION

The current density of the MIS device is due to the TE current can be expressed as [8,25]

$$J = J_o \exp\left(\frac{qV_d}{nkT}\right)\Bigg[1-\exp(-\frac{qV_d}{kT}\Bigg] \tag{1a}$$

where

$$J_o = A^* \, T^2 \exp(-q\Phi_{Bo} / kT) \tag{1b}$$

is the reverse saturation current density, n is the ideality factor, Φ_{Bo} is the zero-bias barrier height, A^* the effective Richardson constant and equals to 32 A cm-^{2} K^{-2} for p-type Si. As shown in Fig. 1, in the range of 0.1V $<V<$0.6 V, the slope of Ln *J-V* curves is almost constant value over the nearly four decades of current and since the Si substrate is lightly doped (1.38 x10^{16} cm^{-3}) then this suggests that trap-assisted multi-step tunneling inside the Si depletion layer of the junction is active conduction mechanism [4]. The J_o was obtained by extrapolating the linear part of Ln *J-V* curve at the intermediate voltage region to zero-applied voltage.

Then the Φ_{Bo} from Eq. (1b) values obtained at each temperature from Eq.(1b) are seen in Table 1. The insulator layer (SiO$_2$) thickness δ was obtained from sufficiently high frequency (500 kHz) *C-V* characteristics as 30 Å by using the equation for insulator layer capacitance of $C_i = \varepsilon_i \varepsilon_o A/\delta$, where $\varepsilon_i = 3.8\ \varepsilon_o$, ε_i and ε_o are the permittivities of the interfacial layer and free space [5]. As can be seen in Table 1, the values of Φ_{Bo} increase with the increase of temperature.

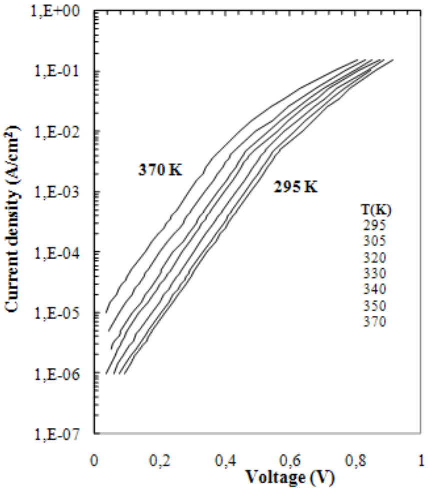

Fig. 1. Forward J-V-T characteristics of the Al/SiO$_2$/p-Si diode.

Table 1

Temperature dependent values of some fundamental parameters of Al/SiO$_2$/p-Si Schottky diodes determined from forward bias LnJ-V characteristics.

T [K]	*n*	J_o [A.cm^{-2}]	Φ_{Bo} (*J-V*) [eV]	Φ_{Bf} (*J-V*) [eV]	*q/nkT* [(eV)$^{-1}$]	N_{ss}(*I-V*) (x10^{13}eV^{-1}cm^{-2})
295	2.22	2.2 x 10^{-7}	0.76	0.947	17.71	4.20 x 10^{14}
305	2.13	2.7x 10^{-7}	0.79	0.944	17.82	3.99 x 10^{14}
320	2.03	4.3 x 10^{-7}	0.81	0.922	17.87	3.61 x 10^{14}
330	1.96	7.3 x 10^{-7}	0.83	0.892	17.93	3.47 x 10^{14}
340	1.90	1.2 x 10^{-6}	0.84	0.888	17.95	3.26 x 10^{14}
350	1.83	2.13 x 10^{-6}	0.85	0.866	18.06	3.08 x 10^{14}
370	1.73	6.55 x 10^{-6}	0.86	0.846	18.16	2.76 x 10^{14}

In order to explain the change in n with temperature a various mechanisms which taking into account the interface state density distribution, quantum mechanical tunneling and image force lowering have been proposed. The TFE mechanism can also be rule out in observed region, since nT is more or less constant in all temperature range. However, Padovani and Stratton [2] have pointed out that TFE could be responsible for current transport mechanism at moderate temperatures and doping levels. The field emission (FE) mechanism becomes important when $E_{oo} \rangle\rangle\ kT/q$, whereas, the TFE dominates when $E_{oo} \approx kT/q$. The values of kT/q are equal to 25.44 meV and 31.91 meV at 295 and 370 K, respectively. The FE becomes important when $E_{oo} \rangle\rangle\ kT/q$, whereas, the TFE dominates when $E_{oo} \approx kT/q$ and thermionic emission-diffusion if $E_{oo} << kT/q$. In the present case, N_A is 1.38.10^{16} cm^{-3} for p-type Si wafer used. Obviously, since $E_{oo} \langle\langle kT/q$ for our sample in the range of temperature used in this work, the possibility of the FE and TFE can easily be ruled out. The above consideration further suggests that tunneling can become important only in highly doped semiconductor having $N_A \geq 10^{17}$ or 10^{18} cm^{-3}. At lower dopant concentrations, tunneling (FE and TFE) current is insignificant and thermionic emission-diffusion (TFD) dominates. The ideality factor n can be further analyzed by plotting E_o versus kT/q. Experimental plots of E_o versus *kT/q* in Fig. 2 suggest that TFE may not be the process responsible for the current transport. The minority carrier diffusion mechanism is also unlikely for our sample, since such mechanism would be expected only for devices having very high effective barrier height values having not very much smaller than that of the band gap of Si and very low reverse saturation current density with temperature independent diode ideality factor having value of almost unity.

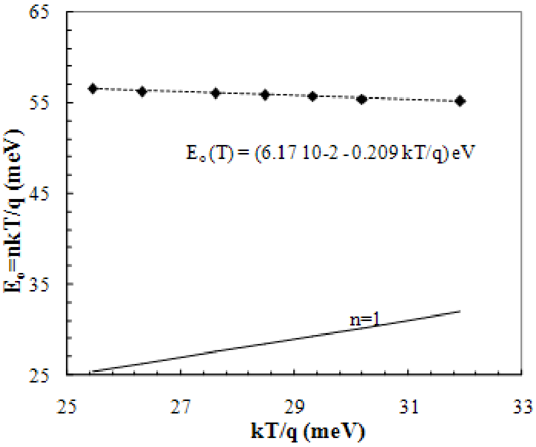

Fig.2. Tunneling current parameter E$_o$ versus kT/q for Al/SiO$_2$/p-Si Schottky diode

5. CONCLUSION

Experimental results show that there was considerable difference between the apparent barrier heights obtained from forward bias *J-V*. In addition the forward bias *J-V* characteristics of MIS Schottky diodes showed unusually linear behaviors in the intermediate bias between 0.1 V and 0.6 V in the temperature region of 295-370 K with an almost temperature independent slope. The values of the ideality factor n controlled by the interface states density were found to be temperature dependent and it was found to change linearly with the inverse temperature. The tunneling parameter E_o and LnJ_o values both extracted from forward bias *J-V* characteristics showed fairly linear behaviors with the temperature indicating that the multistep tunneling might be the possible carrier transport mechanism in our sample [6]. In summary, the analysis of the temperature dependence of the *J-V* characteristics may suggest that, at intermediate forward voltages, the trap assisted multistep tunneling in the silicon space charge region may be the mechanism that dominates the forward current behaviors.

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