Effect on the Electrical Characterizations of Temperature and Frequency Depending on Series Resistance and Interface States in MS Structure

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ABSTRACT

In order to explain the experimental effect of series resistance and interface states of device on current–voltage, capacitance–voltage and conductance–voltage characteritics of Ni/Au/n–Si structure have beeen investigated. Current–voltage characteritics of structure have beeen measuremed in the temperature range of 100K–380K by steps of 40K. In addition, capacitance–voltage and conductance–voltage characteristics of structure have beeen measuremed in the frequency range of 100kHz–1MHz at room temperature. The obtained results show that the Ni/Au/n–Si structure is a good candidate for the electronic device applications.

Keywords: MS Structure, Ni/Au Metal Contact, Electrical Characterizations.

MS Yapısında Ara Yüzey Durumları ve Seri Dirence Bağlı Sıcaklık ve Frekansın Elektriksel Karakterizasyonlar Üzerine Etkisi

ÖZ

Ni/Au/n–Si yapısının akım–voltaj, kapasitans–voltaj ve kondüktans–voltaj karakteristikleri cihazın seri direnç ve ara yüzey durumlarının deneysel etkilerini incelemek için incelendi. Yapının akım–voltaj karakteristikleri 100K–380K sıcaklıkları aralığında 40K lik artışlarla ölçüldü. Ayırca, yapının kapasitans–voltaj ve kondüktans–voltaj karakteristikleri 100kHz–1MHz aralığında oda sıcaklığında ölçüldü. Elde edilen sonuçlar Ni/Au/n–Si yapısının elektronik cihaz uygulamaları için iyi bir aday olduğunu göstermiştir.

Anahtar Kelimeler: MS Yapı, Ni/Au Metal Kontak, Elektriksel Karakterizasyonlar.

1. INTRODUCTION

To date, researchers have been investigated various applications of Silicon (Si)-based structures [1–10]. Studies on the application of these structures are still performed [11–16]. Deposition of metal thin films on Si semiconductor are used in the optoelectronics and microelectronics device applications [1, 3, 6, 17–23], and the quality of metal–semiconductor (MS) structures are especially dependent on the interface states (N_{ss}) between metal and semiconductor and series resistance (R_s) of the structures [1,3]. Therefore, the temperature and frequency dependent electrical characterization of MS structures is of great importance for technological applications to understand the device performance in detail [3, 6]. The temperature dependent analysis give detailed information about the current conduction mechanism and M/S interface [9]. Since current-voltage (I–V) characteristics deviate from linearity at sufficiently high bias voltages due to the effect of R_s. In addition, the values of capacitance (C) and conductance (G/ω) depend on N_{ss} and R_s. Since N_{ss} is a strong function of frequency, it exponentially decreases with increasing frequencies. Therefore, capacitance-voltage (C–V) and conductance-voltage (G/ω–V) characteristics of MS devices are also a strong function of a frequency.

The aim of this work is to investigate temperature and frequency-dependent behaviors of R_s and N_{ss} values of Ni/Au/n–Si structure. I–V measurements of the structure were performed in temperature range of 100–380 K to examine the effect of R_s and N_{ss} on current-voltage-temperature (I-V-T) characteristics. Moreover, C–V and G/ω–V measurements of the structure were performed at room temperature in the frequency range of 100 kHz–1 MHz to examine the effect of R_s and N_{ss} on capacitance–voltage–frequency (C–V–f) and conductance–voltage–frequency (G/ω–V–f) characteristics.

2. EXPERIMENTAL DETAILS

Prior the characterizations, n-type Si substrate (diameter 3 inches) was cleaned using organic solvents for the removal of the native oxide layer. Then, to compare the main electrical parameters, firstly the 1500 Å thick AuGe back metal was deposited at 360 ºC by thermal

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evoparation system. After the metal deposition, alloying for forming the ohmic contact was done by annealing the sample at 310 ºC at 30 second by thermal evoparation system. Then, dot shaped rectifier front contacts with 2 mm diameter and 1500 Å thickness Ni/Au (500 Å / 1000 Å) were formed by deposition of high purity Au and Ni at 70 ºC. The temperature dependent I–V measurements were carried out in the temperature range of 100–380K using a Keithley 2400 source–meter. The temperature was adjusted using Janisvpf–475 cryostat and a Lake Shore model 321 auto–tuning temperature controllers with sensitivity better than ± 0.1 K. The frequency dependent C–V and G/ω–V measurements were performed in the frequency range of 100 kHz–1 MHz by using HP 4192 A LF impedance analyzer. Schematic diagram of Ni/Au/n–Si structure is represented in Figure 1.

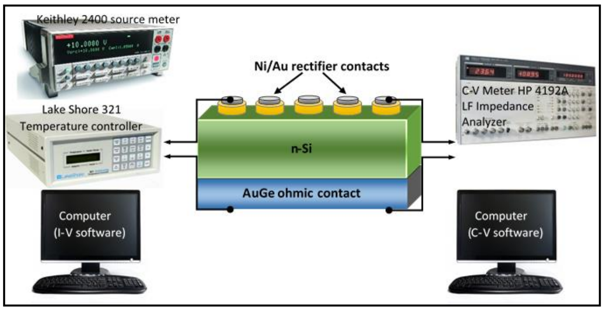

Figure 1. Schematic diagram of Ni/Au/n–Si structure.

3. RESULTS AND DISCUSSION

3.1. Current–voltage characterizations

The experimental I–V data can be analyzed by the following relation [9].

$$I = I_o \exp\left(\frac{qV}{nkT}\right)\left[1-\exp\left(-\frac{qV}{kT}\right)\right] \quad (1)$$

where q is the electronic charge, k is the Boltzmann's constant, T is the absolute temperature in Kelvin and I_o is the saturation current and is expected as

$$I_o = AA^*T^2\exp\left(-\frac{q\Phi_b}{kT}\right) \quad (2)$$

where A is the effective diode area, A^* is the effective Richardson constant and equals to 112 A cm^{-2} K^{-2} for n–type Si. Barrier height (F_b) values can be obtained from Eq. (2). The ideality factor (n) is calculated from the slope of the linear region of the forward–bias I–V curve and is given by

$$n = \frac{q}{kT}\left(\frac{dV}{d(\ln I)}\right) \quad (3)$$

The reverse and forward bias I–V characteristics of Ni/Au/n–Si structure in the temperature range of 100–380 K is given in Figure 2. While the I–V characteristics are linear at low forward bias voltages, they deviate from linearity at high forward bias due to the existence of the R_s and N_{ss}.

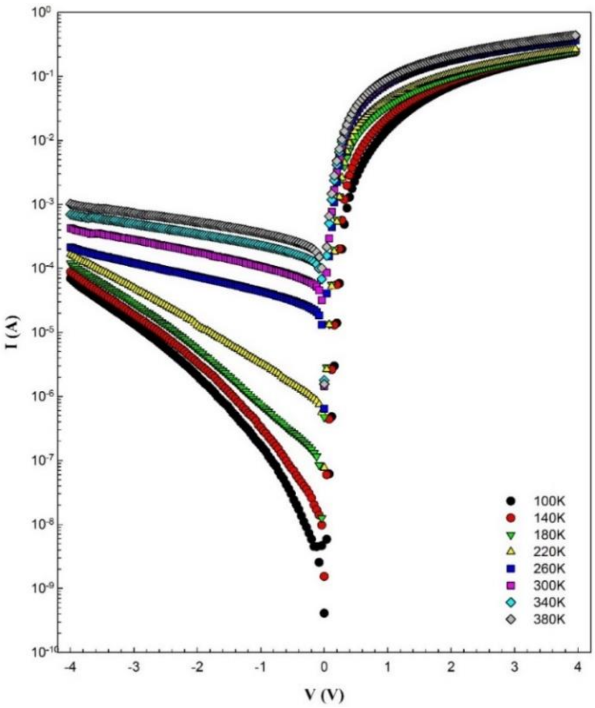

Figure 2. The forward and reverse bias I–V–T characteristics of Ni/Au/n–Si structure in the temperature range 100–380 K.

The experimental values of F_b, n were calculated by using Eq. (2) and Eq. (3) and these values were given in Table 1. An increase in the value of F_b and a decrease in n with increasing temperature are observed.

Table 1. Eelctrical parameter values of Ni/Au/n–Si structure determined from I–V–T characteristics.

T (K)	n	Φ_b (eV)	R_s (Ω)
100	5.45	0.17	16.64
140	5.30	0.21	16.34
180	4.92	0.26	15.78
220	4.46	0.30	14.99
260	3.89	0.35	10.87
300	3.48	0.40	9.88
340	3.13	0.45	9.50
380	2.85	0.51	9.10

R_s values were determined from the structure resistance (R_i) vs applied bias voltage (V_i) plot determined from the I–V characteristics where $R_i = dV_i/dI_i$ and given in Figure 3.

The structure's resistance values approach to a constant value which is R_s, when a sufficiently high forward bias voltage applied. R_s values change from 16.64 Ω to 9.10 Ω at 100 K and 380 K, respectively, and given in Table 1. Similar results have been previously reported in the literature [6, 7].

The expression for N_{ss} as deduced by Card and Rhoderick [24] is reduced as follows [25]. In addition, E_{ss}–E_{ss} values can be obtained from Eq. (2) [25].

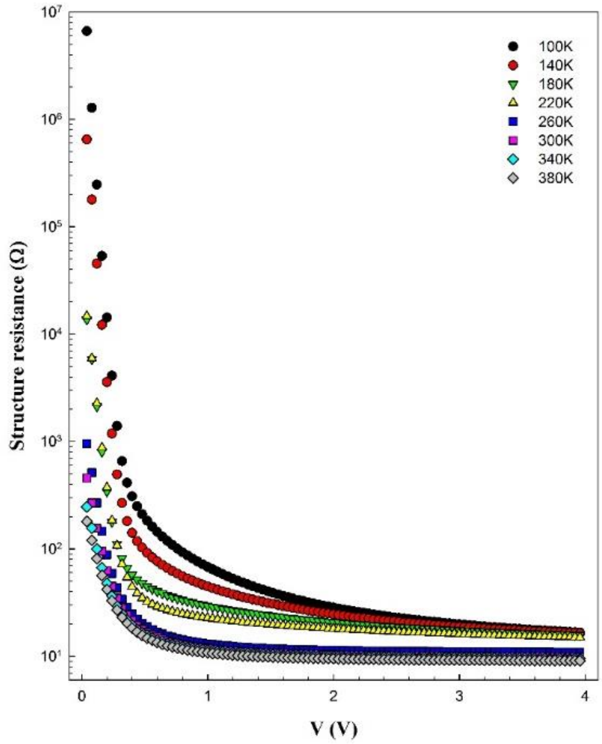

Figure 3. Structure resistance of Ni/Au/n–Si structure in the temperature range 100–380K.

$$N_{ss}(V)=\frac{1}{q}\left[\frac{\varepsilon_i}{\delta}(n(V)-1)-\frac{\varepsilon_s}{W_D}\right] \tag{4}$$

$$E_c-E_{ss}=q(\Phi_e-V) \tag{5}$$

Figure 4 shows the energy distribution profiles of N_{ss} as a function of E_c–E_{ss} extracted from forward bias I–V–T characteristics for 100K, 220K, 260K, and 380K. As shown in Figure 5, N_{ss} values decrease with increasing temperature and are effective in all forward bias regions

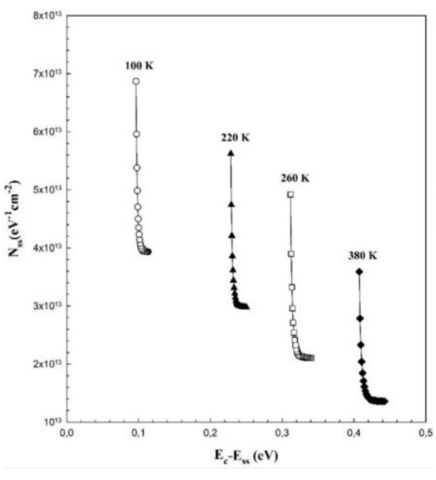

Figure 4. The energy distribution profiles of N_{ss} as a function of E_c–E_{ss} extracted from the forward bias I–V data of Ni/Au/n–Si structure at various temperature.

3.2. Capacitance/Conductance–Voltage Characterizations

C–V–f and G/ω–V–f characteristics was carried out at a frequency of 100, 200, 300, 500, 700 kHz and 1 MHz, and given in Figure 5(a) and (b), respectively.

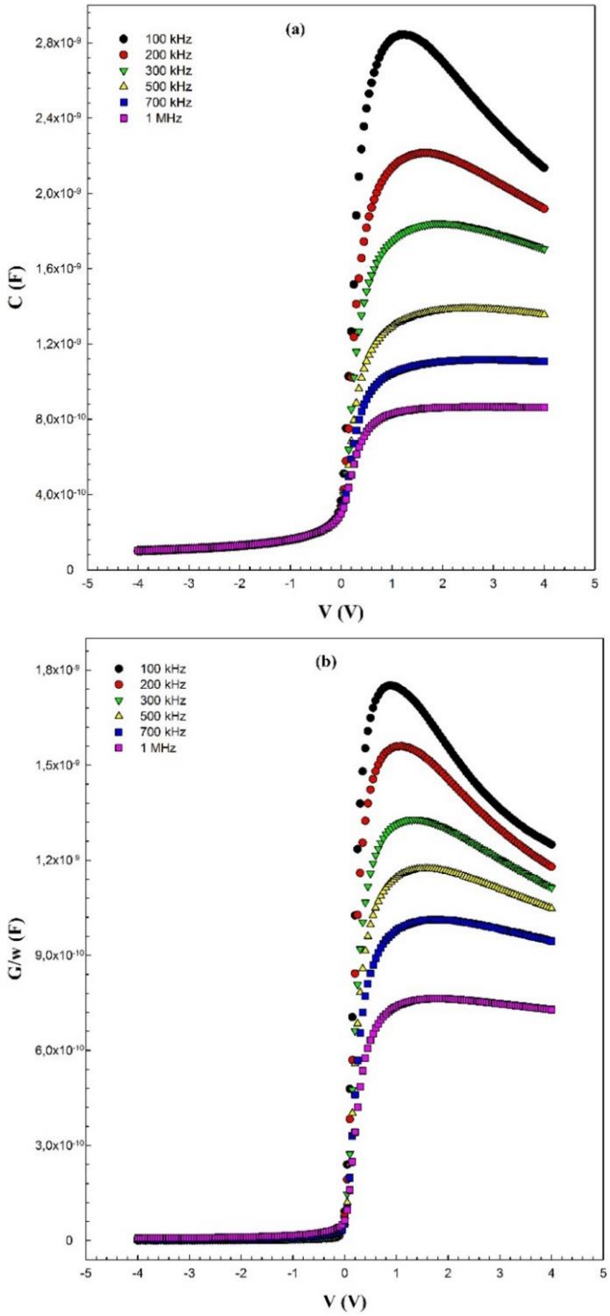

Figure 5. Frequency-dependent **(a)** C–V and **(b)** G/ω–V characteristics of Ni/Au/n–Si structure at room temperature and various frequency

According to Figure 5(a) and (b), capacitance and conductance values increase with the decreasing frequency, especially in the depletion region due to the existence of N_{ss}, while capacitance and conductance values decrease with increasing frequency especially in the accumulation region due to the existence of R_s.

In order to extract the R_s values of the structure, several methods have been suggested in the literature [26–29]. Among all these methods, in our work, Nicollian and Brews method was exploited [26]. To determine the voltage dependency of the resistance (R_i) values, admittance method was developed by Nicollian and Brews [26], and according to this method, R_i values can be determined in the whole voltage range. Thus real R_s values of MS devices can be calculated from the measured capacitance (C_m) and conductance (G_m) in the strong accumulation region using the equation [26]

$$R_s = \frac{G_m}{G_m{}^2 + (\omega C_m)^2} \tag{6}$$

In Figure 6, calculated R_s values for different frequencies were given. As shown in Figure 6, R_s values decrease with increasing frequency.

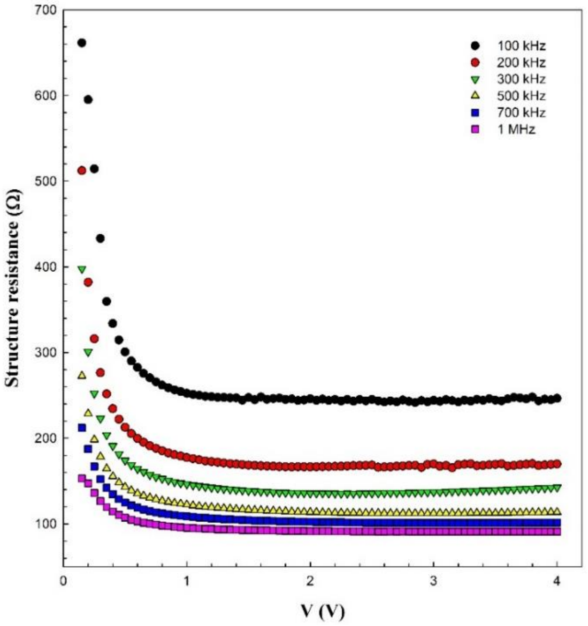

Figure 6. R_s versus V plot of Ni/Au/n–Si structure at room temperature and various frequency.

Figures 7, 8, and 9 show the voltage-dependent C, G/ω, and R_s values obtained from the capacitance–frequency (C–f), conductance–frequency (G/ω–f), and series resistance–frequency (R_s–f) plots for various applied forward–bias voltages (0.1 V to 1.1 V in steps of 0.1 V) at depletion region. It is clearly seen that the values of C, G/ω and R_s decrease with increasing frequencies for each bias voltage value due to the existence of N_{ss}. The changes in the C, G/ω, and R_s values can be attributed to restructuring of the interface charge at the M–S interface.

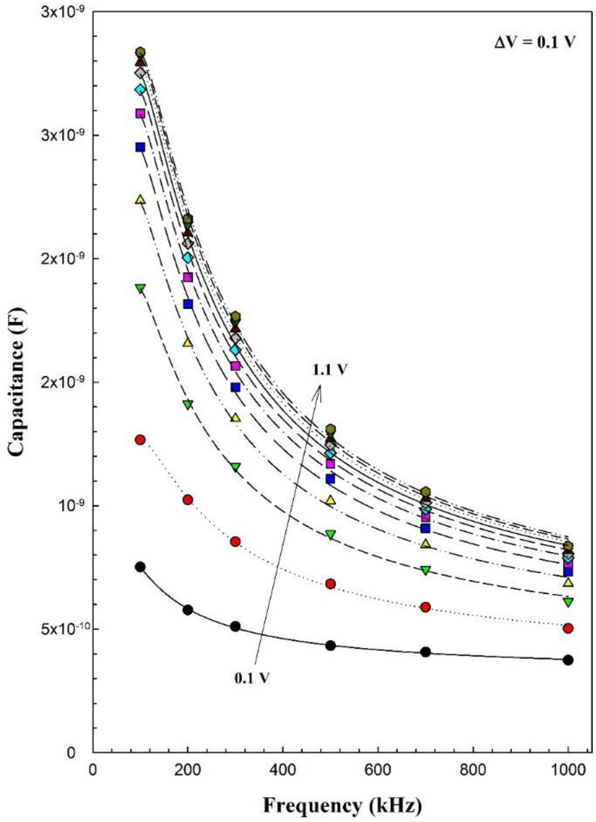

Figure 7. Frequency–dependent capacitance values of Ni/Au/n–Si structure at room temperature and various bias voltage.

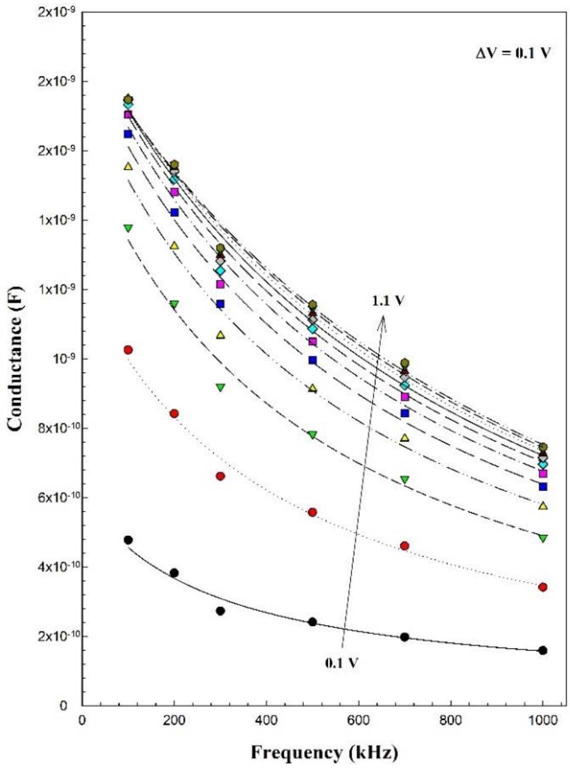

Figure 8. Frequency–dependent conductance values of Ni/Au/n–Si structure at room temperature and various bias voltage.

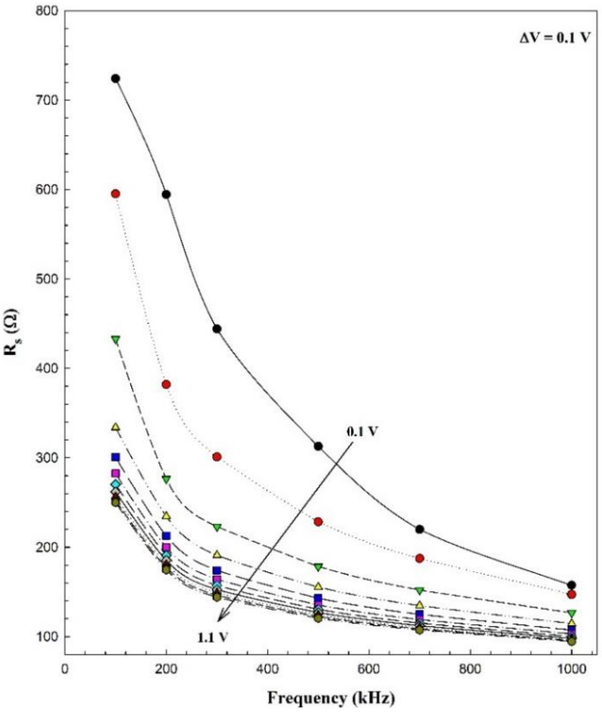

Figure 9. Frequency–dependent series resistance values of Ni/Au/n–Si structure at room temperature and various bias voltage.

Furthermore, frequency dependency of interface states density were obtained using the Hill–Coleman method [30]. According to this method, the N_{ss} values can be calculated by using following equation:

$$N_{SS} = \frac{2}{qA}\frac{(G/\omega)_m}{\left\{\left[(G/\omega)_m/C_i\right]^2+(1-C_m/C_i)^2\right\}} \qquad (7)$$

N_{ss} values were given in Figure 10 for different frequencies (in the frequency range of 100 kHz–1 MHz), and it is seen that N_{ss} values exponentially decrease with increasing frequency. Similar results have been previously reported in the literature [3, 8].

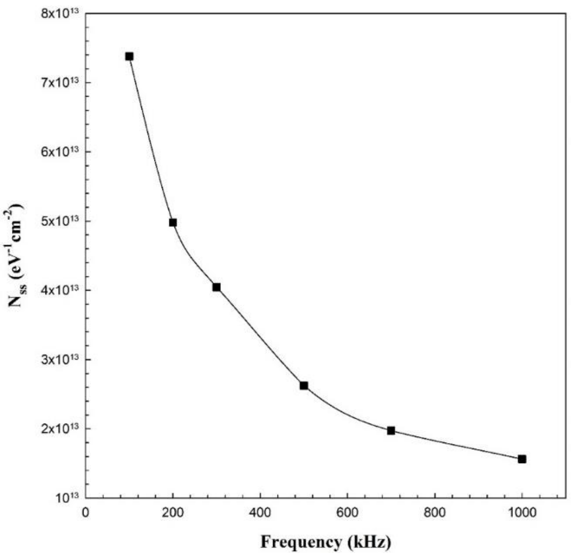

Figure 10. The variation in N_{ss} as a function of frequency for Ni/Au/n–Si structure at room temperature.

In summary, in the present study, the temperature-dependent I–V and the frequency-dependent C–V and G/ω–V characteristics of Ni/Au/n–Si structure were analyzed. The experimental results show that both R_s and N_{ss} are very effective on electrical characteristics. In addition, R_s and N_{ss} values decrease with increasing temperature and frequency.

4. CONCLUSION

In this work, temperature dependency of I–V, and frequency dependency of C–V and G/ω–V characteristics of Ni/Au/n–Si structure has been studied. Ni/Au/n–Si structure with the low R_s values and ideal N_{ss} behavior were observed from the I–V–T measurements in the temperature range of 100–380K. In addition, the ideal R_s and N_{ss} behaviors were observed from the frequency dependent C–V and G/ω–V characteristics in the frequency range of 100 kHz–1 MHz. According to these results, Ni/Au/n–Si MS structure is very promising for novel device design due to its lower series resistance and state-of–the–art energy distribution of the interface states.

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